AL-TR-1991-0109

ARMSTRONG LABORATORY

DEVELOPMENT OF QUANTITATIVE SPECIFICATIONS FOR SIMULATING THE STRESS ENVIRONMENT

James E. Driskell
Brian Mullen
Craig Johnson
Sandy Hughes

Florida Maxima Corporation
147 East Lyman Avenue
Winter Park, FL 32789

Eagle Technology, Incorporated
950 North Orlando Avenue
Winter Park, FL 32789

Cheryl L. Batchelor

HUMAN RESOURCES DIRECTORATE
LOGISTICS RESEARCH DIVISION
Wright-Patterson Air Force Base, OH 45433-6503

March 1992

Final Report for Period July 1989 – May 1991

Approved for public release; distribution is unlimited.

AIR FORCE SYSTEMS COMMAND
BROOKS AIR FORCE BASE, TEXAS 78235-5000

NOTICES

This research was conducted under the Small Business Innovation Research (SBIR) Program as a Phase II effort.

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the Government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder, or any other person or corporation; or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

Cheryl L. Batchelor

CHERYL L. BATCHELOR
Contract Monitor

BERTRAM W. CREAM, Chief
Logistics Research Division

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
March 1992

3. REPORT TYPE AND DATES COVERED
Final July 1989 – May 1991

4. TITLE AND SUBTITLE
Development of Quantitative Specifications for Simulating the Stress Environment

5. FUNDING NUMBERS
C - F33615-89-C-0008
PE - 65502F
PR - 1710
TA - 00
WU - 55

6. AUTHOR(S)
James E. Driskell
Brian Mullen
Craig Johnson
Sandy Hughes
Cheryl L. Batchelor

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Eagle Technology, Inc.
950 North Orlando Avenue
Winter Park, FL 32789

Florida Maxima Corp.
147 East Lyman Avenue
Winter Park, FL 32789

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Armstrong Laboratory
Human Resources Directorate
Logistics Research Division
Wright-Patterson Air Force Base, OH 45433-6503

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AL-TR-1991-0109

11. SUPPLEMENTARY NOTES
Armstrong Laboratory Technical Monitor: Cheryl L. Batchelor, (513) 255-3771.
This research was conducted under the Small Business Innovation Research (SBIR) Program as a Phase II effort.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report is a culmination of work originally started in 1988. The combat maintenance environment is an environment that, to date, has not yet been clearly defined but is extremely important to our success in future combat. These maintenance personnel, although highly trained and skilled technicians, receive little preparation for the extreme stresses of the combat environment. To determine the parameters of that environment, the literature has offered few solutions. However, by utilizing a meta-analytic technique to identify the stress factors that restrict or limit effective performance, we can develop specifications for simulating the stress environment. This report identifies specific ranges to induce stress in the areas of noise, time, pressure, group pressure, threat, uncontrollability, fatigue, dual tasks, and heat and cold. In addition, further research avenues are recommended.

14. SUBJECT TERMS
Combat reaction
Maintenance
Meta-analysis
Psychological stress
Stress

15. NUMBER OF PAGES
214

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PREFACE

The work reported in this technical report was performed by Logicon Eagle Technology Incorporated, and its subcontractor, the Florida Maxima Corporation. This was a Phase II effort conducted under the auspices of the Small Business Innovation Research Program. This work was accomplished under ASD contract F33615-89-C-0008 for the Armstrong Laboratory (AL). Ms. Cheryl L. Batchelor monitored this contract for the Laboratory.

This contract is one of several parts of a more global effort being examined by the AL Operational Logistics Branch. The impact of combat stress on aircraft maintenance personnel is a program which is investigating the feasibility of developing stress reduction methodologies. If the various methodologies proposed prove feasible, follow-on efforts will examine the actual development of specific stress reduction programs. This Phase II effort has shown that specific ranges of various stress factors can be determined using a meta-analytic technique.

SUMMARY

Research from World War II to the present indicates that the stress of combat conditions is a primary source of task and mission performance decrement. Yet, the true test of military systems and personnel is that they operate effectively and efficiently in this environment. One optimal strategy to overcome this degradation is to allow simulation and training of critical skills under the stress operational conditions that personnel will face. This strategy calls for realistic, high fidelity simulations, and has been successful in a variety of military applications. However, although the physical fidelity of a training system can be attained with great precision, there are no design guidelines available for effectively simulating the psychological properties of the stress environment.

This project takes a unique and innovative meta-analytic approach, that has been successfully demonstrated in Phase I, to identify these factors in the combat environment critical to effective maintenance performance. This project develops a set of primary functional specifications, or guidelines, for simulating the stress of the combat maintenance environment. This document can be used in follow-on research to design effective training scenarios and simulations, to develop realistic research settings for the examination of stress effects, and to guide equipment design.

I. INTRODUCTION

Overview

The U.S. Air Force (USAF) will rely on maintenance personnel to support the high rate of sorties required on the future battlefield. However, although maintenance personnel are highly trained technicians, they have little training or tradition to support effective performance under high stress combat conditions. As part of the classic American Soldier studies conducted during World War II, military researchers asked combat veterans from Italy and the North African campaign the question: "What type of training did you lack?" The most frequent response was training under realistic battle conditions (Janis, 1949, p. 229). Exposure to realistic high stress conditions is necessary to prepare personnel to maintain effective performance in combat. However, military and civilian researchers invariably conclude that "we don't know how to effectively manipulate or induce stress."

The search for a reliable and realistic setting to examine performance under stress has led military researchers undersea (Radloff & Helmreich, 1968), aboard airplanes (Berkun, Bialek, Kern, & Yagi, 1962), into firetowers (Berkun et al., 1962), to parachute school (Burke, 1980), and into combat (Williams, 1984). Training exercises that are available to simulate a stress environment, such as the "gas chamber" drill used for chemical defense training by all military services, are based primarily on perceptions of physical fidelity to the stressor environment. For example, the gas chamber procedure for chemical defense simulation is based on a procedure designed in World War I for the purpose of building performance confidence in this environment. However, research data suggest that the training effectiveness of such a procedure may be woefully inadequate (Driskell, 1984; 1986). Other stress simulations designed to enhance performance in the operational environment are usually based on intuitive guidelines of what constitutes realistic stress conditions, and are also likely to be of questionable effectiveness.

In defining a maintenance simulation, the researcher can provide the engineer with precise specifications for physical parameters. For example, the simulation may require specific test equipment and a certain type of display. However, when asked to provide information on the parameters required to simulate the stresses of combat, the researcher can often provide only a broad and subjective reply. The purpose of this research project is to provide some initial answers to this problem. This project uses a meta-analytic statistical technique to integrate and summarize research on stress factors that may limit or degrade effective performance in the combat environment. Questions addressed include the following:

What are the factors that determine a reliable and effective stress environment?

How do we effectively simulate the stress environment for training and/or research?

How do we induce or manipulate specific stressors for maximum effect?

What factors have been shown to moderate the effects of stress on task performance?

This project constitutes the first comprehensive attempt to map stress effects across a wide variety of stressors through a uniform quantitative procedure. The results provide practical and precise data for simulating the stress environment.

Background

Few individuals become accustomed to emergency, hazardous, or extreme stress conditions, simply because such situations are rare. For example, military personnel rarely experience an intense combat surge. Nuclear power plant workers are seldom faced with the extreme stress conditions of a nuclear incident. Yet, we know the potential for serious error that these types of situations engender; e.g., risky decisions are made, skilled performance declines, and crucial information is ignored (see Foushee, 1984). In these situations, where performance is crucial, military personnel must be prepared to perform under hostile, extreme stress conditions. The effects of stress on task performance, and the mitigation of these effects, are areas of critical concern to the military.

The problem of maintaining effective task and mission performance under stress has been consistently identified as a priority area for military research (Driskell & Olmstead, 1989; Driskell & Salas, 1991). Stress was identified as a priority focus for military research as early as 1917 (Yerkes, 1918); and as recently as 1988, a chapter in the National Research Council report Enhancing Human Performance was devoted to the management of stress (Druckman & Swets, 1988). Regardless of the extent of technological advancements made to enhance the performance of military personnel, the problem of maintaining effective task performance in a stressor environment will remain.

In fact, the complexity of modern military systems and the intensity of the high-technology battlefield may cause combat stress to become an even more significant factor in mission performance. Today's sophisticated military systems are evidence that the person-machine system is the fundamental military unit. Even with advances in system capabilities, the individual plays an increasingly critical role in the operation and maintenance of military systems. The impact of stress on the combat maintenance environment may negate technological advances that have been achieved in combat systems, because the overall system performance is jeopardized when the human component is degraded.

The effects of stress on task performance is a primary concern of the Department of Defense (DOD) for several reasons. First, the military operational environment is, by definition, a high stress environment. Both personnel and equipment must be prepared to operate efficiently in this combat environment, which is the true test of military preparedness.

Second, the effects of stress on performance are profuse and well documented. Research has identified numerous effects of stress, including: physiological arousal such as increased heartbeat, labored breathing, and trembling (Rachman, 1983); motivational losses (Innes & Allnutt, 1967); increased self-monitoring (Carver, Blaney, & Scheier, 1979); stressor aftereffects (Cohen, 1980); cue restriction and narrowing of the perceptive field (Combs & Taylor, 1952; Easterbrook, 1959); decreased search behavior (Streufert & Streufert, 1981); longer reaction time to peripheral cues and decreased vigilance (Wachtel, 1968); degraded problem-solving (Yamamoto, 1984); performance rigidity (Staw, Sandelands, & Dutton, 1981); and even lowered immunity to disease (Jemmott & Locke, 1984). Data show that performance stress alone may increase errors on operational procedures threefold (Villoldo & Tarno, 1984). Similarly, Idzikowski and Baddeley (1983) found that the time to complete manual tasks doubled under stress conditions.

The magnitude of this problem has been recognized for some time, particularly in the area of combat performance (Marshall, 1947; Schwartz & Winograd, 1954). For example, stress effects during the Normandy campaign in World War II were such that,

> ...the [combat] soldier was slow-witted; he was slow to comprehend orders, directions, and techniques. Memory defects became so extreme that he could not be counted upon to relay a verbal order. (Siegel et al., 1981, p. 13)

A final reason for the DOD's historical emphasis on stress research is that failure to consider and prepare for the effects of stress on military performance exacts a high price. That is, stress-induced decrements in performance are most likely to occur when they can be least tolerated: during critical combat situations. Performance in a high stress environment may degrade even the best-trained unit; however, it will eliminate the untrained unit.

Historically, however, the military has conducted little research to examine stress in the <u>combat maintenance environment</u>. With the notable exception of a program of research addressing aircraft maintenance units (see Batchelor, 1988; Kane, 1986), one would have to assume by the amount of research devoted to this area that maintenance personnel are less vulnerable to stress effects than aircrews or infantry. Several reasons suggest why this assumption may be a critical mistake:

1. Maintenance tasks that involve complex cognitive skills are more vulnerable to degradation from stress than more labor-intensive tasks. For example, French (1983), examining the

performance of military personnel using speech recognition systems, found that recognition rates declined when the operators were placed under stress. Villoldo and Tarno (1984) found that procedural errors made by explosive ordnance disposal personnel increased by a magnitude of three when the operators were under stress. The impact of stress on degrading the performance of complex tasks such as those routinely performed by combat maintenance personnel is likely to be significant.

2. The USAF relies on effective maintenance to generate sorties and maintain mission performance. There are several trends in the combat maintenance environment that are likely to increase the potential for significant combat stress effects, including (a) continued increases in system complexity; (b) the requirement to sustain intense combat surges of up to 72 hours, with corresponding high sortie rates; and (c) dispersed basing and mobile teams. Yet, maintenance is often treated as a "given" when the future battlefield is considered.

Experts predict that the combat stress casualty rate will be 25 percent of total casualties or higher on the high-intensity, high-technology battlefield of the future. These estimates are derived largely from observations of infantry troops. Batchelor (1988) notes that if we expect trained combat troops to sustain this degree of degradation from stress casualties, the impact on combat maintenance personnel, who are not hardened combatants, will likely be much greater.

3. In past conflicts, maintenance tasks were performed in the rear of the forward line of battle. In the future battlefield, there will be no identifiable rear, and maintainers will perform under the most extreme conditions imaginable. However, maintainers have no tradition of performance in the face of combat, no role models, no weapons, and little preparation for this environment. In discussing maintenance performance on the flightline, Jones (1987) concludes that, "Our people in the Air Force cannot shoot back. They are all combat support...They do not have the release of being able to fire back. They have got to get out and read a checklist while people are threatening their lives" (p. 125).

4. Finally, maintainers do not train for combat. The Army infantry uses the Multiple Integrated Laser Engagement System (MILES) to exercise under simulated combat conditions. Pilots use sophisticated simulators and emergency training programs such as Situational Emergency Training (SET) to practice under stress conditions. Maintainers train for peacetime conditions rather than for wartime. Even the Instructional Systems Development (ISD) approach that is used to develop military training is couched in non-combat terms. For example, a training standard might read, "Given an oscilloscope, the trainee will be able to troubleshoot..." More realistically, the standard should read, "Given an oscilloscope, threat conditions, time pressure, and fatigue, the trainee will be able to troubleshoot..." As summarized by the military panel investigating the USS Vincennes

incident, training most often occurs in a calm and rehearsed environment, which is quite unlike that faced under operational conditions (House Armed Services Committee, 1989).

In summary, combat stress has been recognized as a critical area of military research for some time, as evidenced by research carried out by American researchers (Burke, 1980; Driskell, Moskal, & Carson, 1987) as well as by Israeli (Friedland & Keinan, 1986), British (Labuc, 1984), and Soviet (Solov'yeva, 1981) researchers. In summarizing this threat, a recent report from the U.S. Army School of Advanced Military Studies concluded: "Combat stress will be one of the most significant causes of loss of manpower" (Coomler, 1985, p. 34). This opinion is supported by Navy researchers who claim, "During critical periods of a mission, susceptibility to (psychological) threat may be the decisive factor between success or failure" (Wherry & Curran, 1966, p. 228).

Problem

Research and observation confirm that combat stress plays a major role in the operational military environment. Therefore, in order to maintain performance in this environment, should not stress factors be critical elements in the design of simulation and training for combat maintenance personnel?

The DOD faces the problem of maintaining effective task and mission performance under high stress combat conditions. One crucial component in maintaining personnel performance in a stress environment is to exercise critical tasks under operational conditions similar to those likely to be encountered in the real environment. Training that allows the simulation of novel or high stress environmental conditions has been successful in a variety of military applications including water survival, escape training, and firefighting. Thus, "realistic" training and simulation is recognized as one critical instructional strategy to prepare personnel to operate in the stress environment.

However, there is little available information on how to create these training conditions. That is, there is little empirical guidance available on how to effectively simulate a stress environment for training purposes, or how to design training systems for specific stressor environments. The conclusion from a recent National Research Council report on the topic states:

> Although the stress effects occurring in real environments are purported by military and civilian managers to be an important factor in realistic training...there exists a lack of understanding of stress that occurs or can be induced in simulations. Very little research has addressed problems in this area. (Jones, Hennessy, & Deutsch, 1985, p. 63)

Other researchers have noted that no adequate database on human performance under stress is available to guide applied efforts. Wickens and Rouse (1985) conclude:

> When a system designer wants to know how far 45 percent of the pilot population can reach, before a control's location is established in the cockpit, the figure is available from a database on human anthropometry. But when the designer wants to know...how the operator's mental model of a computer-based automated system is affected by fatigue, only the fuzziest of answers may at present be provided. (Wickens & Rouse, 1985, p. 6)

State-of-the-art simulation and training techniques can reproduce a specific operational environment with extraordinary physical fidelity. A maintenance trainer or a training mockup can be developed with exact spatial, aural, and visual specifications for training. Yet, when we attempt to develop a "stress training overlay" for that system, or try to develop the functional specifications for a "stressor environment" for training and/or research purposes, guidance on how to design this innovation is at best ad hoc and intuitive rather than systematic and theory-based. That is, researchers can effectively design the physical fidelity of a training system, but reaching the goal of psychological fidelity in simulating a stress environment is a more difficult task.

In most cases, the military researcher or training developer is forced to design a stress scenario or stress environment in terms of individual reactions to it in an ex post facto manner (i.e., they design a stress environment on intuitive grounds and then assess individuals' reactions), or the researchers or designers simply project what they think would be stressful (i.e., they define a situation as stressful because they assume it would be stressful to <u>them</u>). In most cases, they end up with a situation or training scenario with physical fidelity and face validity (i.e., it "looks" like a stress environment), but little psychological fidelity (i.e., it does a poor job of inducing stress).

The result is that the military researcher has few specific procedures and few specific tools to provide maintainers that will help overcome stress degradation and sustain task performance in the critical combat environment.

<u>Objectives</u>

The overall goal of this project is to enhance maintenance performance in the combat environment.

The technical objectives of this work are:

1. to identify what psychological stressors (threat, uncontrollability, time pressure, noise, etc.) may be effective in simulating stress in a reliable manner;

2. to identify the extent to which each stressor affects performance;

3. to identify the most effective means to manipulate each stressor;

4. to identify factors that moderate (increase or decrease) stress effects; and

5. to develop a precise set of guidelines for simulating the stress environment.

II. TECHNICAL APPROACH

The combat environment is one of the few settings universally acknowledged to generate extreme stress. Military combat is the proving ground of military preparedness. The goal of military manpower and equipment preparedness is to win the next war. Thus, the "bottom line" of military preparedness is the level of individual performance under the stress of combat conditions.

Research has shown that, for some tasks, normal training procedures (practice conducted under normal non-stress conditions) do not improve task quality when the task has to be performed under stress conditions (Zakay & Wooler, 1984). These results suggest that, under certain conditions, transfer of training from classroom conditions to conditions on the battlefield may be poor, without stress-inclusive simulations or training. Thus, one component of effective training systems is to prepare individuals to perform critical mission tasks under the high stress operational conditions with which they will be faced. Combat simulations or training exercises that allow personnel pre-exposure to the stress operational environment should reduce the extent of performance decrement encountered in the actual combat setting. This strategy has been successful in a number of military applications, including water survival, flight emergency training, and firefighting.

In most cases, a training situation is designed with a certain degree of physical and psychological fidelity to facilitate the transfer of training to the actual task setting. However, these training simulations vary in effectiveness. Training situations such as a firefighting simulation, for example, may provide a very effective and realistic exposure to the stress performance environment it was designed to simulate, although indications are that the chemical defense "gas chamber" drill used by all the military services does a poorer job. What are the factors that allow one scenario to be an effective training system, while the other fails? How does one setting effectively simulate the stress environment, while the other does not?

Figure 1 presents a model of the effects of stress on task performance. The research literature documents a number of factors that constitute stress stimuli. These stress factors include perceived threat, noise, perceptions of uncontrollability, time pressure, fatigue, heat stress, and other factors identified in Column 1 of Figure 1. These stress factors produce a number of measurable effects, including increased errors, decreased speed of performance, subjective or psychological stress, and so forth. These effects are organized into the three categories in Column 3 of Figure 1: performance speed and accuracy, psychological effects, and physiological effects. There have been literally hundreds of studies performed within this research domain. However, because different studies are conducted in different settings, use different outcome

Environmental Stressors	Moderators	Outcome Measures
Time Pressure	Intensity	Performance Speed
Noise	Predictability	
Threat	Uncontrollability	Performance Accuracy
Heat/Cold	Duration of Exposure	
Fatigue		Psychological Effects
Circadian Effects	Type of Task	
Group Pressure		Physiological Effects
Dual Task Performance		
Isolation		

Figure 1. Model of stress and performance

measures, and report different study statistics, it is difficult if not impossible to integrate these disparate research studies on an intuitive level, in order to provide the military or civilian researcher specific information or guidelines on stress effects.

The approach undertaken in this project is a meta-analytic integration of the research on stress and performance. Meta-analysis allows the results of a number of independent studies to be analyzed, compared, and summarized. For example, a number of studies have examined the effects of noise on performance. Some research has found that noise degrades performance. For example, Finkelman et al. (1979) found that noise increased the incidence of errors on a short-term memory task. Other studies, however, have found that noise enhances performance. Kirk and Hecht (1963) discovered that noise facilitated the performance of a vigilance task. An astute reviewer may be able to estimate, in general, the direction and magnitude of effect of the relationship between noise and

performance from the preponderance of evidence across most studies. However, it is difficult to make a confident prediction, because of the variety and types of data reported in these different studies. Glass (1976) concurs that, "The accumulated findings of [independent] studies should be regarded as complex data points, no more comprehensible without statistical analysis than hundreds of data points in a single study" (p. 352).

The goal of this project is to specify the relationship between each stressor (such as noise) and each outcome measure (e.g., the relationship between noise and performance accuracy, noise and performance speed, noise and subjective stress, and so on). This approach will allow us to analyze the results of research within each research domain (noise, time pressure, threat, etc.), and develop summary statistics of strength and significance of effect for each particular stressor.

Perhaps more important, this approach allows us to examine variables in the literature that moderate each stressor-outcome relationship (see Column 2 of Figure 1). For example, certain factors, such as how the stressor is manipulated, the range of manipulation, the mode of delivery, etc., may <u>increase</u> the strength of the stress effect. It is important to identify such specific factors in order to develop a strong and effective simulation of the combat environment. On the other hand, certain other factors, such as the type of task, may <u>lessen</u> the effects of that stressor on performance. This information is also crucial in order to enhance performance in the stress environment.

In summary, this approach will allow us to (a) identify those stress factors which are critical for effectively simulating the combat stress environment; (b) identify specific effects of these stressors on task performance, psychological reactions, and physiological reactions; (c) identify moderators of these stress effects; and (d) specify how to manipulate relevant stressors to achieve an effective combat stress simulation. Rather than simply conducting yet another study to examine how, for example, time pressure impacts performance, this approach is designed to integrate and leverage the large body of research on stress and performance that has been conducted by the Army, Navy, Air Force, and civilian institutions over the past several decades. The results of this meta-analytic research will provide specific guidelines for inducing and manipulating stress.

The following description outlines the meta-analytic procedure to be used to provide this data.

<u>Method</u>

It is informative to provide a distinction between <u>primary analysis</u>, <u>secondary analysis</u>, and <u>meta-analysis</u>. Primary analysis refers to the original statistical analysis of data; for example, the analysis of data collected by a researcher examining the effects of noise level on performance errors. Secondary

analysis refers to the analysis of data by someone other than the original researcher, with theoretical goals and/or analytic techniques that may differ from those of the original researcher. For example, investigator B may re-analyze investigator A's data on noise and performance to examine a particular variable of interest. Meta-analysis refers to the analysis of the results of several independent studies. For example, if investigators A through Z have conducted 30 studies of the effects of noise on performance errors, a meta-analysis would provide a numerical summary and integration of the results of these separate studies. For example, Mullen, Salas, & Driskell (1989) have recently conducted a meta-analysis of the research literature examining the relation between participation rates and leadership behavior. This analysis integrated the results of 33 separate hypothesis tests, and represented the behavior of 3,611 subjects in 830 groups.

Procedures for combining and comparing the results of independent studies have existed for quite some time (e.g., Fisher, 1932, 1938; Mosteller & Bush, 1954; Pearson, 1933; Rosenthal, 1961; Snedecor, 1946; Thorndike, 1933). However, it was not until Gene Glass (1976) labeled this perspective as "meta-analysis" that this approach received the popularity and currency it enjoys today. Meta-analysis generally refers to the statistical integration of the results of independent studies. The term, meta-analysis, does not describe a single statistical procedure which distills a domain of research into one simple answer. Rather, meta-analysis embodies a constellation of different statistical techniques, developed and suited for specific purposes, and a general conceptual approach to the problem of summarizing, integrating, and testing practical questions and theoretical issues with the results of previous research.

Procedurally, there are several distinct steps in the development of a responsible and informative meta-analytic integration. These steps are outlined in Table 1.

Step 1. Specify the Hypothesis to be Tested. Consider that the broad interest of the researcher is on the effects of stress on performance. The first step in performing a meta-analysis is to define carefully and precisely the specific hypothesis test to be examined. The specific operationalizations of the independent and dependent variables must be clearly articulated. For example, given the present concern with the effects of stress upon performance, the specific operationalizations of stress to be examined within a particular analysis must be explicit.

There are literally hundreds of studies (a considerable proportion of which have been funded or performed by various branches of the Armed Forces) which have examined the effects of some component of stress on some type of performance outcome. As represented in Figure 1, there are a number of distinct, broad classes or components of stress: time pressure, threat, noise,

TABLE 1. OUTLINE OF THE META-ANALYTIC PROCEDURE

1.	Specify the hypothesis to be tested.
2.	Define criteria for including studies in the analysis.
3.	Conduct search for relevant research.
4.	Obtain and review research.
5.	Extract data for statistical analysis.
6.	Obtain predictors of study outcomes.
7.	Conduct statistical analysis.
8.	Interpret results.

temperature, fatigue, etc. There are nearly as many different performance outcomes: performance speed, performance accuracy, self-reported or perceived stress, and a plethora of physiological responses. Attempts to integrate the effects of noise on self-reported tension from one study with the effects of time pressure on performance accuracy from another study would be impractical. These different components of stress are likely to exert different effects on different performance indicators, and to be moderated by different constellations of intervening variables. However, little practical value would be derived from such a heavy-handed integration of the effects of "stress" broadly defined. Such an ill-defined type of integration might present some general picture of the effects of stressors, but it would not specify how different components of stress independently contribute to different performance indicators.

Rather than attempting to examine the effects of "stress" broadly defined, we will analyze separately each independent variable or stressor identified below:

1. Threat. Almost all definitions of stress include the concept of threat: the fact that stressors threaten the individual's physical or psychological well-being. This threat is paramount in the military combat environment. In fact, military researchers in World War II concluded that the central fact of combat was danger to life and limb (Williams, 1984). The capability to effectively simulate the danger and threat of this environment is critical.

2. Uncontrollability. Whether or not the individual can manipulate or control the environment is a significant determinant of stress. For example, researchers have found that

individuals in an overcrowded elevator experience a much less negative reaction if they are able to stand next to the control panel than if they do not have this perceived ability to control their environment. This phenomenon is particularly important to the combat maintenance environment because maintenance personnel must perform a task under very hostile conditions and yet are not issued weapons to respond to attack. It is likely that this inability to manipulate or respond to the external stressor environment is a significant factor in combat maintenance performance.

3. Fatigue. In combat, maintenance personnel will be forced to respond to intense combat surges of up to 72 hours while maintaining high sortie rates. Of special concern is the mental or cognitive fatigue resulting from sustained performance over time.

4. Circadian Rhythms. One factor that may interact with fatigue is circadian or time-of-day effects. The disruption of circadian rhythms and work efficiency by continuous operations is a significant factor in combat performance.

5. Time Pressure. Time pressure has a severe effect on decision making and accuracy of performance. Research has shown that under time pressure, task performers make poorer decisions and more errors. It has been suggested that under time pressure, individuals tend to conserve on cognitive activity, preferring simple task strategies over more complicated procedures--a proposition that has significant implications for the performance of complex tasks.

6. Group Pressure. Individuals may train alone, but they often work together, or at least interact with and work among others on the battlefield. Research has shown significant effects of working alone versus working among or in the presence of others who serve as potential distractors.

7. Noise. The effects of noise, both continuous and variable, on task performance are broad, ranging from increased accidents to impaired judgment. Noise may result in impaired attention, increased operator errors, impaired recall, poor communication, and fatigue.

8. Climatic Conditions. Although heat and cold affect performance differently, both can greatly impair skilled behavior. Several factors, including length and intensity of exposure, combine to determine the human thermal state and the subsequent ability to perform.

9. Dual Task Performance. Personnel in a combat environment are not only under greater time pressure than in normal conditions, but they are also likely to be performing concurrent tasks. The effects of dividing attention on dual tasks are likely to impair performance.

Two other stressors were initially reviewed but dropped from further analysis: the effects of isolation on the battlefield

(the perceptual isolation identified by Marshall (1947) and others) and the effects of malodorous pollutants (the ambient smells of combat). There was not enough relevant empirical research within these areas to support statistical analysis.

After the independent variables of interest have been identified, then we must specify the dependent variables to be examined. In this case, the specific operationalizations of "performance outcome" to be examined within each integration must be explicit. Rather than trying to examine the effects of stress on performance broadly defined, we will examine separately the specific subcomponents of performance delineated in Figure 1, including performance speed and performance accuracy.

In this manner, we derive a number of specific and unambiguous hypotheses to be examined meta-analytically. For example, we will examine the effects of noise on performance accuracy, and identify variables that influence or determine this relationship. We will examine separately the effects of noise on performance speed, and identify variables that influence or determine this relationship. We will examine separately the effects of noise on self-reported or subjective stress, and identify variables that influence or determine this relationship. The goal is to specify each of the stressor/outcome measure links illustrated in Figure 1. In the following, we describe briefly each outcome measure.

1. Performance Speed. Many studies examine the effects of a particular stressor on the time required to perform a task. If the task is a reaction type task, this measure may be the reaction time to respond to a stimulus; if the task is a problem-solving task, this measure may be the time required to solve the problem.

2. Performance Accuracy. Many studies examine the effects of a particular stressor on performance accuracy. Accuracy is typically assessed by the number of errors incurred on a task.

3. Subjective Stress. Subjective or self-reported stress includes an individual's perception of threat, anxiety, or stress. These measures typically access how stressed the subject felt under the test conditions.

4. Physiological Measures. Physiological measures include measures of heart rate, heart rate variability, blood pressure, galvanic skin response, EMG level, catecholamine and corticosteroid output, skin temperature, blood glucose level, palmar sweating, the P300 evoked potential response, muscle tension, eye blink and eye blink duration, respiration rate, and a host of other measures.

The wide variety of physiological measures evident in this literature posed a problem for the meta-analysis, which we solved (somewhat regrettably) by dropping physiological measures from the analysis. The problem was thus. By carefully and precisely defining each specific hypothesis to be tested (see steps 1 and

2), we identified a limited set of empirical studies that were relevant to each hypothesis (such as those studies that assess the effects of time pressure on performance). We were then able to examine each subset of studies that dealt with time pressure and performance speed (that is, there were a number of studies that used a speed of performance measure as an outcome measure), and with time pressure and performance accuracy (that is, there were a number of studies that used some type of error rate as an outcome measure). However, when examining the effect of almost any particular stressor on physiological reactivity, we were faced with a multiplicity of outcome measures. For example, we may find four instances in which the effect of time pressure on heart rate was assessed, three instances in which the effect of time pressure on muscle tension was assessed, two instances in which the effect of time pressure on galvanic skin response was assessed, and so on. It is not defensible to combine these into some composite physiological measure because they are all conceptually different. Nor is it reliable to perform separate meta-analyses on each subset of studies with so few cases (i.e, the four studies that report heart rate or the three studies that report muscle tension). Therefore, we decided to focus on performance speed, performance accuracy, and subjective stress because the outcome measures within these areas were conceptually similar. Physiological measures were omitted from the analysis.

Step 2. Define Criteria for Including Studies in the Analysis. At this point, we are able to define the specific criteria for including studies in each meta-analysis. Consider the dual-task analysis. There are scores of studies that examine some aspect of dual-task performance. However, our primary interest in this project is whether dual-tasks can be implemented effectively as a stressor in a stress simulation. Therefore, we include in this analysis only those studies that provide a specific comparison of single-task versus dual-task performance. (This is a simplification; see Section 9 for the exact criteria for inclusion in the dual-task analysis.)

This step, which is performed concurrently with Step 1, allows us to achieve two objectives. First, it allows us to specify a precise hypothesis even more precisely. For example, one hypothesis to be examined becomes the effects of single-task versus dual-task performance on performance accuracy. We include in our analysis only those studies that report a test of this hypothesis, so that we avoid mixing "apples and oranges" in the analysis. Second, it makes an extensive literature (such as the noise literature) manageable by delimiting the specific relationship of interest. For example, within the noise domain, we only included studies in the meta-analysis if they reported results of a noise versus a no-noise (control) condition. This approach eliminated a number of studies that tested noise effects, but were tests of different hypotheses (such as a comparison of continuous versus variable noise or a comparison of noises of differing frequencies).

Step 3. Conduct Search for Relevant Research. After a well-defined hypothesis test has been identified, the relevant studies must be located and retrieved. Relevant studies may appear in published academic journals, scholarly textbooks, unpublished papers presented at conferences, unpublished theses and dissertations, and published and unpublished technical reports. Several distinct strategies were employed to locate relevant studies. The Ancestry approach uses the bibliographies and reference sections of relevant studies which have already been retrieved to locate earlier relevant studies. The Descendency approach uses indexing sources (such as Social Sciences Citation Index) to retrieve subsequent relevant studies which have cited earlier relevant studies. Abstracting Services (such as the Defense Technical Information Center (DTIC) and PSYCHINFO) identify studies through a computer-based search associated with key words and phrases. All three approaches (Ancestry, Descendency, and Abstracting Services) can be conducted via on-line computer databases. The "Invisible College" approach refers to the informal network of scientists working on a given problem. Letters, phone calls, and conversations with researchers most active in a particular research domain can sometimes uncover new, unpublished studies at various stages of completion.

At this stage, we choose to cast a wide net in order to retrieve relevant studies within each domain. For example, we performed an initial computer search using the term "noise stress" as a keyword. This approach uncovered literally hundreds of studies on some aspect of noise stress. At this point, we reviewed each study description and omitted those that were obviously irrelevant (i.e, those studies conducted with rats or that contained no empirical data). Therefore, the goal of Step 3 is to identify all studies that may be potentially relevant to the hypothesis to be tested, and then reduce these studies into a smaller subset of relevant studies using the criteria established in Step 2.

Step 4. Obtain and Review Research. We then obtained these studies by ordering them from the relevant source (such as DTIC or Dissertation Abstracts), copying them from the appropriate journal, or requesting otherwise unaccessible reports from the author. At this point, there were only two limits to obtaining relevant studies: (a) they must be in the English language, and (b) in some cases, reports from DTIC were of restricted distribution. Again, studies were excluded from analysis if they did not meet our explicit criteria for inclusion.

Step 5. Extract Data for Statistical Analysis. Once the relevant studies have been retrieved, the appropriate tests of the hypothesis under examination must be derived from each study report. Sometimes this approach is perfectly straightforward. Very often, however, researchers will report study statistics in a form that does not allow us to test the specific hypothesis under examination. For example, researchers will sometimes identify the difference between two means as "significantly

different" without reporting a statistical test of the difference. Similarly, researchers will sometimes report an F-test based on more than 1 degree of freedom in the numerator, which actually tests the hypothesis of whether any of several conditions differ in any way from any of the other conditions. This approach may have suited the purposes of the original researcher, but for the purposes of testing whether two specific conditions differ as required by the hypothesis that we wish to examine, this type of statistic is not useful.

Based on an understanding of primary-level inferential statistics, the meta-analytic researcher can often reconstruct the original statistical test of the hypothesis. This reconstruction of the desired test of the hypothesis is not simple, but it is perfectly straightforward if the proper amount of information is presented in the original study. In those instances of imprecisely reported hypothesis tests, we can often reconstruct the original analyses from reported means, standard deviations, and other related but different F-tests. In cases in which this information is not available for reconstruction, we must exclude that study from the analysis.

<u>Step 6. Obtain Predictors of Study Outcomes</u>. Studies vary in terms of the effect of X on Y. For example, one study may report a strong effect of time pressure on performance accuracy and another study may report a much weaker effect. In some cases, we may account for this variability by examining factors that moderate the effect of time pressure on performance. For example, certain factors, such as how the stressor is manipulated, may increase or decrease the strength of the stress effect. At this stage, we attempt to identify variables within each study domain that predict the effects of the independent variable. Based on theoretical as well as on practical guidance, we can code or rate studies according to the presence of these potential moderators.

<u>Step 7. Conduct Statistical Analysis</u>. In this step, we analyze the results from each study that dealt with a particular hypothesis test. For each hypothesis (e.g., the effect of time pressure on performance accuracy) there might be 5 to 50 hypothesis tests (i.e., there might be 5 to 50 instances in which this relationship was empirically examined) involving from 50 to several thousand subjects. The meta-analytic statistics are derived from these hypothesis tests.

Of course, one study may report a t-test, a second study may report a chi-square, a third study may report a correlation coefficient, and so on. Because these statistics are on different metrics, they must be transduced to more standard, common metrics. The two common metrics for statistical results are significance levels (Z and one-tailed p) and effect size (Fisher's Z, r, r^2, and d). Once placed on common metrics, the significance levels and effect sizes of separate hypothesis tests can be combined, compared, and examined for the fit of predictive models. At this point, we are able to answer two basic

questions. The first question concerns central tendency--what is the average effect of X on Y? Basic meta-analytic combinations of significance levels and effects sizes provide a gauge of the overall combined probability and strength of the effect of that component of stress on that performance indicator. The second question is related to prediction--how do we account for the variability around the average result? Meta-analytic focused comparisons provide a gauge of the extent to which the effect of a stressor on performance increases or decreases as a function of some theoretically relevant or practically important moderator (formulae and computational procedures for these meta-analytic techniques are presented in Mullen, 1989; Mullen & Rosenthal, 1985; Rosenthal, 1984).

This step was aided considerably by a computer-based meta-analytic statistical package and database management system developed by Brian Mullen (Mullen, 1989). This system allowed us to not only use a standardized analysis protocol for each domain, but also to avoid errors attributable to hand-calculation of very complex formulae.

Step 8. Interpret Results. This strategy presents the opportunity to do two very useful things. First, it can provide a very specific and precise summary of the overall effects within a given research domain. For example, by analyzing each study that has examined the effects of noise on performance speed, we can provide summary statistics indicating the magnitude and significance of this effect. Second, this strategy allows us to test specific models and theoretical assumptions which would be exorbitantly expensive, or practically impossible, to examine at a primary level of analysis. For example, we are able to examine the effects of factors that may moderate the effects of noise on performance speed, such as the mode of presentation or the effects of continuous noise versus noise bursts. This approach can provide valuable practical information on how to effectively manipulate these variables.

III. NOISE

Introduction

The noise of the combat battlefield can be debilitating, and may serve as a major source of combat stress. Research from World War II indicates that the fear of enemy weapons was often disproportionate to the actual threat presented by that weapon; soldiers often feared the sound of a weapon more so than its effectiveness. For example, although the German 88-mm gun used in World War II was unquestionably a dangerous and effective weapon, the majority of soldiers reported that they feared it because of "the sounds it produces--when it goes off and when the shell is traveling through the air" (Stouffer et al., 1949, p. 237). Similarly, most soldiers reported that they feared the dive bomber because of its "terrible shrieking noise" (p. 234).

This chapter examines the non-auditory effects of noise. The term "non-auditory" generally refers to the psychological effects of noise. This analysis excludes research that examines the effects of noise on sensory functions such as hearing loss, depth perception, or visual acuity, and excludes research which examines the role of noise in directly masking desired sound. This approach is similar to that taken by other researchers interested in the effects of noise on general human performance (see Cohen & Weinstein, 1981; Grether, 1971; Kryter, 1971; Loeb, Jones, & Cohen, 1976).

From one of the earliest studies of the effects of noise on performance (Cassel & Dallenbach, 1918) to the more recent (Albery, 1989), the noise literature has been marked by a consistent inconsistency of results. Some research has found that noise degrades performance. For example, Finkelman et al. (1979) found that noise increased the incidence of errors on a short-term memory task. Other studies, however, have found that noise enhances performance. Kirk and Hecht (1963) discovered that variable noise facilitated the performance of a vigilance task. Finally, some studies have shown that noise has no effect on performance. Gardinier (1971) found no positive or negative effect of noise on performance of a psychomotor task.

What Coates and Alluisi (1975) refer to as the schizophrenic nature of findings in this area is illustrated by the following statements.

> In general, the investigations have shown that noise has a deleterious effect on human performance. (Fornwalt, 1965, p. 2)

> [Investigators] have generally failed to demonstrate any impairment other than impairments of hearing and of inter-personal communication. (Loeb, Barron, & Burda, 1954, p. 3)

> There is a growing body of knowledge which has demonstrated both negative and positive effects of noise. (Repko, Brown, & Loeb, 1974, p. 2)

> Surprisingly little useful information has resulted from this research. The findings have ranged from adverse effects through no effects to beneficial effects on performance. (Thackray & Touchstone, 1979, p. 1)

> Despite the fact that noise effects on performance have been the topic of many studies, results have been contradictory and difficult to generalize. (Cohen, Conrad, O'Brien, & Pearson, 1974, p. 1)

> No generalizations can be made; noise may or may not have a disruptive influence upon behavior. (Wilbanks, Webb, & Tolhurst, 1956)

> Perhaps the only conclusion one can reach from reading reviews of the effects of noise on human performance is that there are effects. Whether these effects are detrimental or facilitative...remain largely undetermined. (Harris, 1968, p. 16)

> The specific effect of noise stress on human performance is...elusive. (Albery, 1988, p. 140)

These comments document that the state of knowledge regarding noise and performance, assessed by the above authors from 1954 through 1988, is hardly settled. This may not be an entirely negative consequence; researchers in the field may argue that this variability in research findings reflects the wide range and diversity of research being conducted in this area. However, for those interested in practical applications (particularly the applied researcher interested in the effects of noise as a stressor), this ambiguity poses some real problems. Foremost is the question of how to manipulate noise in a reliable and effective manner. Gardinier (1971) faced this exact problem in her research, noting that "the choice of type and level of noise to be used in this experiment was somewhat difficult" (p. 7).

Cohen et al. (1974) conclude that the effects of noise on performance are difficult to predict, and are dependent on a number of factors including intensity of the noise, temporal characteristics such as intermittency and duration, and the nature of the task. The purpose of this analysis is to specify the relationship between noise and performance, and to examine the factors that moderate or determine this relationship.

Nature and Theory of Noise Effects

Noise researchers commonly make a distinction between sound and noise. Sound is a physical phenomenon, referring to changes in air pressure detected by the ear. Noise, on the other hand, is a psychological concept, defined as "unwanted sound" (Cohen & Weinstein, 1981), or as an auditory stimulus that bears no

task-related information (McCormick & Sanders, 1982). Noise cannot be defined strictly in physical terms, because, for example, a particular engine sound may provide useful information to a technician, whereas it may simply represent an unwanted roar to someone attempting to speak over a phone.

Sound is produced by the variations in sound pressure made by a vibrating surface (such as a drum). These vibrations travel at about 1,100 feet per second to reach the human ear. The variations in pressure emanating from a sound source produce cycles of compressed and rarefied molecules, which can be plotted as alternating excursions or waves above and below normal pressure.

Sound waves vary in two primary ways. The number of complete cycles of pressure variation per second (one cycle is one complete sequence or wave from high pressure to low to high again) represents the frequency of a sound. Frequency is measured in cycles per second, or hertz (Hz). The normal range of human sensitivity to sound ranges from 20 to 20,000 Hz. Frequencies above this range are called ultrasonic and those below 20 Hz are called infrasonic. (These terms are not to be confused with the terms supersonic and subsonic, which refer to the speed of sound.) Changes in frequency are perceived as changes in pitch, with lower frequencies representing a lower-pitched tone and higher frequencies representing a higher pitch. Most of the sounds we hear contain a wide range of frequencies, often termed broad-band or white noise.

The amount of pressure variation above and below normal pressure levels is reflected in the height, or amplitude of a sound wave. Changes in amplitude are perceived as changes in loudness. The unit of measurement for specifying loudness is the decibel (dB). The bel (B) is a basic unit of measurement named after Alexander Graham Bell; a decibel (dB) is 1/10 of a bel. Zero on this scale corresponds to the normal hearing threshold for a 1,000-Hz tone (the frequency at which the ear is most sensitive).

There are no instruments available for directly measuring sound energy. However, since sounds are pressure waves, variations in air pressure can be measured by sound-level meters. Sound-pressure meters may use one of three different weighting networks (A, B, or C) because of the fact that the ear is not equally sensitive to all frequencies of sound. Most studies use the A-level standard (reported for example as 50 dBA) because of its accuracy in predicting a subjective response to noise.

Common examples of sound pressure levels are illustrated in Table 2.

There are several major theories that explain the effects of noise on performance. Broadbent (1971) claims that exposure to noise results in increased arousal. Heightened arousal leads to a narrowing of attention, resulting in a restricted range of information processing. While low levels of arousal may

TABLE 2. DECIBEL LEVELS FOR VARIOUS SOUNDS

Sound Pressure Level	Source
50-60 dB	Ambient noise, quiet environment
60-70 dB	Normal speech
70-80 dB	Freight train at 100 feet
80-90 dB	Subway train at 20 feet
90-100 dB	Pneumatic hammer
130 dB	Jet aircraft at 35 feet

actually lead to improved performance (as only irrelevant stimuli may be ignored), higher arousal results in the task performer ignoring task relevant cues or information. Therefore, according to Broadbent, decrements in task performance are attributable to overstimulation. Introducing noise will raise an individual's arousal level either to an optimal level or to a level of arousal high enough to overload or degrade one's information processing capacity. Poulton (1978) argues that the effects of noise on performance may be related to arousal, but that arousal subsides quickly after the onset of noise (he also argues that this initial arousing effect is often beneficial to performance).

Poulton maintains that decrements in task performance, particularly under continuous noise conditions, are a function of the masking of acoustic cues, or even the masking of the "inner speech" of a task performer. In other words, people either can't hear subtle task relevant cues in the presence of noise, or they can't "hear themselves think." He further argues that detrimental effects of intermittent noise on performance are often simply the result of distraction.

According to the distraction-arousal theory (Teichner, Arees, & Reilly, 1963), noise has two primary effects: it can distract the task performer or increase the level of arousal. Loeb, Jones, and Cohen (1976) note that while it is important to understand the underlying theoretical mechanisms that account for noise effects, this goal may be premature since the effects themselves are often in dispute.

Moderators

The effect of noise on performance may be moderated by several factors including intensity, temporal characteristics of the noise such as intermittency and duration, mode of delivery, and the type of task.

Intensity. Most research indicates that the effects of noise on performance increase in severity as a function of loudness. However, there is considerable ambiguity over the level at which noise produces a discernable decrement in performance. For example, Fornwalt (1965) offers the position that noise of less than 90 dB may have no effect on performance, then notes that this position has not yet been firmly established. Broadbent (see Harris & Filson, 1971) has argued that noise of 100 dB or more should be used. Weinstein (1974; 1977), on the other hand, found that 68 dBA noise impaired performance on a cognitive task. Specifying the effect of noise intensity on performance is important because this will provide the stress researcher with information on the noise level required to produce a significant performance effect. More specifically, it is important that we specify the level of noise required to exert a measurable degradation on performance; yet at the same time not choose an arbitrarily high level of noise intensity because of the potentially damaging effects of noise on hearing loss.

Intermittency. The intermittency of noise can be described by the relationship between the parameters of duration and periodicity. Duration is the time period over which the noise occurs; periodicity is the repetition rate, or the time from the beginning of one noise episode to the beginning of another. A noise with equal duration and periodicity times (i.e., a noise of 5 seconds duration that repeats after every 5 seconds) represents a continuous noise. With any duration/periodicity ratio between zero and one (i.e., a noise of 5 seconds duration that repeats every 10 seconds), the noise is described as intermittent. Since intermittent noise may be more distracting (Poulton, 1978) and impose more of an information load on the performer (Coates & Alluisi, 1975) than continuous noise, many researchers argue that intermittent noise has a more negative effect on performance. However, some data suggest that intermittent noise may both enhance (Warner & Heimstra, 1971) as well as degrade performance (Theologus, Wheaton, & Fleishman, 1974; Eschenbrenner, 1971).

Duration. Studies vary in the duration of the noise presented. Whereas in one condition of Warner and Heimstra (1972), 100 dB noise was presented for 100 seconds; in Warner and Heimstra (1971) a similar noise was presented for 4.8 seconds. Since noise may serve to overload the task performer, the duration of the noise event may moderate performance effects.

Mode of Delivery. Hartley (1976) argues that noise presented over headphones may have less of an impact than noise presented in a "free field" (in most studies, free-field noise is that presented over speakers). In support of this claim, he notes that free-field noise is generally perceived as louder than noise of the same pressure level presented via headphones. On the other hand, he notes that headphones may mask subtle acoustic cues related to task performance more effectively than free-field noise. In this case, headphones may contribute to increased task impairment relative to free-field noise.

Type of Task. Almost all reviews of the effects of noise on performance make claims relating to the effect of noise on specific tasks. For example, McCormick and Sanders (1982) state that cognitive tasks are most sensitive to disruption by noise. Yet, reviewers, if they support their claim at all, often offer a limited set of studies as evidence. For example, McCormick and Sanders cite Weinstein (1974; 1977) as evidence of the susceptibility of cognitive tasks to noise. However, we can as easily refer to other studies (such as Smith & Broadbent, 1981) that do not support this position.

Cohen and Weinstein (1981) claim that psychomotor tasks are unlikely to show noise-induced impairment; a claim that has been empirically supported by Harris (1973). Theologus et al. (1973) suggest that psychomotor tasks may be less sensitive to noise effects than cognitive tasks. Coates and Alluisi (1975) conclude from a review of relevant studies that noise has no effect on vigilance performance (see also Koelega, 1986). Allen, Magdaleno, and Jex (1975) claim that minimal effects are obtained with reaction time tasks.

Cohen and Weinstein (1981) note that although psychologists have studied the impact of noise on a wide range of tasks, the probability is small that there is reliable evidence relating noise to a particular task of interest. However, this information is of critical practical importance if the stress researcher is to choose an experimental task that is sensitive to noise effects. In the following analysis, we will examine the effects of noise on performance separately for perceptual, reaction, vigilance, psychomotor, short-term memory, and cognitive tasks.

Procedure

Consistent with the procedure specified in Chapter II of this report, an exhaustive search was conducted to identify studies on noise and performance utilizing several specific search techniques. Using computer-based abstracting services, we searched the DTIC and PSYCHINFO databases. Using the ancestry approach, we searched the bibliographies and reference sections of selected reports and articles to identify previous relevant studies. Using the descendency approach, we used indexing sources such as the Social Science Citation Index to locate relevant studies cited in earlier references. Plus, we manually searched major technical journals to identify relevant articles.

Studies were included in the meta-analysis if they reported the effects of a relatively high noise level versus that of a relatively low noise level on performance (speed or accuracy) or self-reported stress. Studies were eliminated from consideration if the basic statistical information required for analysis was not retrievable. Many of the DTIC reports identified in this search were also published as articles in academic journals (i.e., Hartley, 1974, in the *Journal of Experimental Psychology*,

is also published as DTIC ADA027142); data from these redundant reports were not duplicated in the analysis.

We analyzed the effects of noise separately for three outcome measures. The first measure analyzed was performance accuracy (i.e., number of errors). The studies in the analysis yielded a total of 122 hypothesis tests for the effects of noise on accuracy. The second outcome measure analyzed was speed of performance. (Broadbent, 1957, and others have argued that while task performers tend to produce more errors in the presence of noise, they maintain the same speed of performance.) The studies in the analysis yielded a total of 29 hypothesis tests for the effects of noise on speed. Finally, we examined the effects of noise on self-reported stress. The studies in the analysis yielded a total of 13 hypothesis tests for the effects of noise on self-report. The hypothesis tests included in this meta-analysis are presented at the end of this chapter.

Results

General Effects. Table 3 presents results of the analysis of 122 hypothesis tests of the effect of noise on performance accuracy. These results indicate that the effects of noise on accuracy are significant ($p < .001$) and of weak to moderate magnitude ($r = -.140$).

The fail-safe number presented in Table 3 and in similar subsequent tables is informative. Calculation of the fail-safe number addresses one objection to the meta-analytic procedure: that, for example, whereas the present analysis shows a significant general effect of noise on performance accuracy based on 122 hypothesis tests, there may be other "undiscovered" studies (unpublished or otherwise inaccessible) that show no effect, that if discovered would produce a different result. The fail-safe number in Table 3 indicates that it would take 5,475 hypothesis tests that show no effect to reduce the overall probability level reported in this analysis to the $p = .05$ level. In other words, it would take 5,475 studies showing no effect to overturn the results of this analysis.

Table 4 presents results of the analysis of 29 hypothesis tests of the effect of noise on performance speed. These results indicate that the effects of noise on speed are nonsignificant ($p = .464$) and of negligible magnitude ($r = .005$).

Table 5 presents results of the analysis of 13 hypothesis tests of the effect of noise on self-reported stress. These results indicate that the effects of noise on self-report are significant ($p < .001$) and of strong magnitude ($r = -.558$).

TABLE 3. GENERAL COMBINATIONS OF SIGNIFICANCE LEVELS AND EFFECT SIZES: NOISE AND PERFORMANCE ACCURACY

122 Hypothesis Tests (weighted by sample size)

Combination of Significance Levels
Z for combination = -7.229
Associated one-tailed $p < .001$
Fail-safe number ($p = .05$) = 5,475

Combination of Effect Sizes
Mean Fisher's Z = -.141
Mean $r = -.140$
Mean $r^2 = .020$

TABLE 4. GENERAL COMBINATIONS OF SIGNIFICANCE LEVELS AND EFFECT SIZES: NOISE AND PERFORMANCE SPEED

29 Hypothesis Tests (weighted by sample size)

Combination of Significance Levels
Z for combination = .091
Associated one-tailed $p = .464$
Fail-safe number ($p = .05$) = ---

Combination of Effect Sizes
Mean Fisher's Z = .005
Mean $r = .005$
Mean $r^2 = .00002$

TABLE 5. GENERAL COMBINATIONS OF SIGNIFICANCE LEVELS AND EFFECT SIZES: NOISE AND SELF-REPORTED STRESS

13 Hypothesis Tests (weighted by sample size)

Combination of Significance Levels
Z for combination = -15.317
Associated one-tailed $p < .001$
Fail-safe number ($p = .05$) = 1,142

Combination of Effect Sizes
Mean Fisher's Z = -.631
Mean $r = -.558$
Mean $r^2 = .312$

In sum, there is a strong negative relationship between noise and perceived stress; people respond to noise stress by feeling tense, annoyed, and anxious. There is a weaker, yet significant, negative relationship between noise and performance accuracy; people respond to noise stress with more errors. There is no evident general relationship between noise and performance speed. The relationship between speed and accuracy is consistent with that suggested by several researchers. Broadbent (1957), Repko et al. (1974), and others have observed that individuals often produce more mistakes in the presence of noise, yet are able to perform at the same rate of speed.

Mode of Delivery. Table 6 presents the results of separate combinations of significance levels and effect sizes, and the corresponding focused comparisons, for hypothesis tests in which noise was presented via headphones, and for hypothesis tests in which noise was presented via speakers.

TABLE 6. RESULTS OF COMBINATIONS AND FOCUSED COMPARISONS FOR MODE OF DELIVERY

	Self-Report	Speed	Accuracy
Headphones			
Significance Levels			
Z	13.693	.561	3.578
p	<.001	.288	<.001
Effect Sizes			
Z	-.718	.016	-.095
r	-.616	.016	-.094
r^2	.379	.0002	.009
Speakers			
Significance Levels			
Z	7.172	.848	6.358
p	<.001	.198	<.001
Effect Sizes			
Z	-.486	-.043	-.175
r	-.451	-.043	-.173
r^2	.204	.001	.030
Focused Comparison			
Z	.400	.504	3.629
p	.345	.307	<.001

For self-report, the general effect (shown in Table 5) for individuals to report greater stress under noise conditions differs slightly for headphones versus speakers. Table 6 indicates a tendency for individuals to become more annoyed, or report greater stress, when noise is presented via headphones ($r = -.616$) than when noise is presented via speakers ($r = -.451$), although this trend is not significant ($p = .345$).

For performance accuracy, the general trend for performance to be impaired by noise was exaggerated by speakers ($r = -.173$) and mitigated by headphones ($r = -.094$); this comparison is significant ($p < .001$). There is no effect of mode of delivery on performance speed.

In summary, we find a significant focused comparison for performance accuracy: people perform more poorly when noise is presented by speakers. Although the pattern of results is not significant for self-report, it is in the opposite direction. In other words, we get a stronger aversive self-report of stress with headphones, but we get a stronger performance impairment with speakers.

Intermittency. Table 7 presents the results of separate combinations of significance levels and effect sizes, and the corresponding focused comparisons, for hypothesis tests in which noise was presented continuously, and for hypothesis tests in which noise was presented in bursts.

For self-report, there is a stronger aversive response to bursts ($r = -.605$) than to continuous noise ($r = -.438$), although this trend is not significant ($p = .391$).

For performance speed, there is a tendency for individuals to do worse (slow down) when noise is continuous ($r = -.093$) and better (speed up) when noise is presented in bursts ($r = .092$). This comparison approaches significance ($p = .064$). There is no effect of noise presented continuously versus that presented in bursts for performance accuracy.

Intensity. Table 8 presents the correlation between Z for effect size and decibel level as well as the corresponding focused comparison of effect sizes for self-report, speed, and accuracy. For self-report, the correlation between effect size and decibel level is quite large ($r = -.845$). The Z for focused comparison is 7.37, and the probability associated with this Z is significant ($p < .001$). Therefore, noise results in greater self-reported stress as the decibel level increases.

For performance accuracy, there is a weak correlation between decibel level and effect size ($r = -.108$) approaching significance ($Z = 1.589$, $p = .056$). Therefore, there is a slight tendency for individuals to perform more poorly as decibel level increases.

The impairment in performance speed does not appear to be related to the decibel level of the noise ($r = .164$, $Z = .930$, $p = .176$).

TABLE 7. RESULTS OF COMBINATIONS AND FOCUSED COMPARISONS FOR INTERMITTENCY (CONTINUOUS VERSUS BURSTS)

	Self-Report	Speed	Accuracy
Continuous			
Significance Levels			
Z	6.666	1.621	3.082
p	<.001	.052	.001
Effect Sizes			
Z	-.470	-.094	-.103
r	-.438	-.093	-.103
r^2	.192	.009	.011
Bursts			
Significance Levels			
Z	13.894	1.596	7.523
p	<.001	.0552	<.001
Effect Sizes			
Z	-.701	.092	-.197
r	-.605	.092	-.194
r^2	.366	.008	.038
Focused Comparison			
Z	.278	1.522	.727
p	.391	.064	.234

TABLE 8. CORRELATIONS BETWEEN DECIBEL LEVEL AND EFFECT SIZE, AND FOCUSED COMPARISONS OF EFFECT SIZES

	Self-Report	Speed	Accuracy
r	-.845	.164	-.108
Focused Comparison			
Z	7.370	.930	1.589
p	<.001	.176	.056

Therefore, the louder the noise, the more stress you'll feel; to a lesser degree, the more poorly (in terms of accuracy) you'll perform. However, when we examine the effects of decibel level according to the mode of delivery (Table 9), we find that these overall effects for speed and accuracy seen in Table 8 are masking important differences that occur as a function of the mode of delivery (headphones versus speakers). For speed, as the decibel level of noise increases over headphones, the better (more quickly) individuals work ($r = .288$); however, as the decibel level of noise increases over speakers, the worse (more slowly) they work ($r = -.448$). Therefore, what seems to be no apparent effect of decibel level on performance speed in the overall analysis in Table 8 is in fact the result of a small-to-moderate positive effect for headphones and a moderate-to-large negative effect for speakers.

TABLE 9. CORRELATIONS BETWEEN DECIBEL LEVEL AND EFFECT SIZE, AND FOCUSED COMPARISONS OF EFFECT SIZES BY MODE OF DELIVERY

		Self-Report	Speed	Accuracy
Headphones				
	r	-.895	.288	.014
Focused Comparison				
	Z	6.493	1.420	.096
	p	<.001	.078	.462
Speaker				
	r	-.850	-.448	-.160
Focused Comparison				
	Z	2.594	1.297	2.191
	p	.005	.097	.014

This analysis uncovers a somewhat similar trend for accuracy: although there is little effect of increased decibel level when noise is presented via headphones ($r = .014$), as the decibel level of noise increases over speakers, the worse individuals perform ($r = -.16$). Therefore, for accuracy, what seems to be a weak overall effect of decibel level on performance is a combination of no effect for headphones and a small-to-moderate negative effect for speakers.

For self-report, there is no difference in the effects of decibel level on perceived stress by mode of delivery;

individuals respond aversely to increasing noise levels presented by headphones as well as speakers.

In Table 10, we examine the effects of decibel level based on the intermittency of the noise (continuous versus bursts). We again find that the effects of decibel level on self-report are robust; there is a strong effect of increasing decibel levels on self-report regardless of whether the noise is presented continuously or in bursts. For speed and accuracy, the pattern of noise (continuous versus burst) does not seem to moderate the relationship between decibel level and performance. In summary, what seems to be important in terms of maximizing the effects of loud or intense noise is the mode of delivery (headphones versus speakers), not whether the noise is presented in bursts or continuously.

TABLE 10. CORRELATIONS BETWEEN DECIBEL LEVEL AND EFFECT SIZE, AND FOCUSED COMPARISONS OF EFFECT SIZES BY INTERMITTENCY

		Self-Report	Speed	Accuracy
Continuous				
	r	-.877	.330	-.091
Focused Comparison				
	Z	2.544	.765	1.076
	p	.005	.222	.141
Bursts				
	r	-.895	.151	-.112
Focused Comparison				
	Z	6.544	.788	1.013
	p	<.001	.216	.156

Duration. Table 11 presents the correlation between Z for effect size and duration, as well as the corresponding focused comparison for effect sizes for self-report, speed, and accuracy. Overall, we find no general effect of duration on self-report ($r = .129$, $p = .165$), speed ($r = -.069$, $p = .356$), or accuracy ($r = -.077$, $p = .121$). Therefore, in general, longer exposure to noise does not worsen the effects.

TABLE 11. CORRELATIONS BETWEEN DURATION AND EFFECT SIZE, AND FOCUSED COMPARISONS OF EFFECT SIZES

	Self-Report	Speed	Accuracy
r	.129	-.069	-.077
Focused Comparison			
Z	.973	.368	1.169
p	.165	.356	.121

However, Table 12, which examines the effect of duration by mode of delivery, illustrates that duration does have effects under specific conditions. For self-report, when noise is presented through speakers, longer exposure to noise reduces the stress an individual feels ($r = .759$, $p = .009$). In other words, when noise is presented via speakers, individuals are able to habituate to the noise effects, at least cognitively.

TABLE 12. CORRELATIONS BETWEEN DURATION AND EFFECT SIZE, AND FOCUSED COMPARISONS OF EFFECT SIZES BY MODE OF DELIVERY

	Self-Report	Speed	Accuracy
Headphones			
r	-.047	-.102	.165
Focused Comparison			
Z	.314	.500	1.434
p	.377	.308	.076
Speaker			
r	.759	-.158	-.100
Focused Comparison			
Z	2.384	.351	1.208
p	.009	.363	.113

For accuracy, the almost non-existent general effect of duration on performance masks opposing effects of duration when noise is presented by headphones versus speakers. Thus, there is a tendency for longer noises presented via headphones to improve accuracy ($r = .165$) and for longer noises presented via speakers to degrade performance accuracy ($r = -.1$). These contrasting

results suggest one way in which noise affects the individual. In summary, as the duration of noise (presented via speakers) increases, individuals report less stress; but as the duration of noise increases, individuals tend to make more errors. This relationship suggests that individuals are able to habituate cognitively to the effects of noise over time, perhaps by restricting or blocking out environmental inputs. However, as task-relevant information (or attention to the task) is blocked out, task performance is also degraded.

Table 13 examines the effects of duration when the noise is presented in bursts versus when it is presented continuously. For self-report, as we would expect, the longer a noise is presented in a continuous manner, the less stress the individual feels (i.e., the easier it is to habituate) ($r = .877$). However, the individual is not able to habituate to noise over time when it is presented in bursts ($r = -.05$). The intermittency of the noise also mediates the effect of duration on performance speed. When noise is presented continuously, the individual performs more quickly over time ($r = .337$); however, when noise is presented in bursts, the individual performs more slowly over time ($r = -.386$). A similar trend is observed for performance accuracy, although intermittency has the opposite effect. When noise is presented continuously, the individual tends to make more errors ($r = -.136$); however, when noise is presented in bursts, over time the individual performs more accurately ($r = .068$).

<u>TABLE 13.</u> CORRELATIONS BETWEEN DURATION AND EFFECT SIZE, AND FOCUSED COMPARISONS OF EFFECT SIZES BY INTERMITTENCY

		Self-Report	Speed	Accuracy
Continuous				
	r	.877	.337	-.136
Focused Comparison				
	Z	2.544	.823	1.659
	p	.005	.205	.049
Bursts				
	r	-.052	-.386	.068
Focused Comparison				
	Z	.350	1.867	.543
	p	.363	.031	.294

Type of Task. Table 14 presents the results of separate combinations of significance levels and effect sizes for hypothesis tests involving perceptual, reaction, vigilance, psychomotor, short-term memory, and cognitive tasks.

TABLE 14. RESULTS OF GENERAL COMBINATIONS AND COMPARISONS BY TYPE OF TASK

		Speed	Accuracy
Reaction			
	k	2	1
Significance Levels			
	Z	-.884	-7.623
	p	.188	<.001
Effect Sizes			
	Z	-.190	-.464
	r	-.188	-.433
	r^2	.035	.188
Vigilance			
	k	---	11
Significance Levels			
	Z	---	-1.236
	p	---	.208
Effect Sizes			
	Z	---	-.076
	r	---	-.076
	r^2	---	.006
Psychomotor			
	k	4	21
Significance Levels			
	Z	-1.49	-3.583
	p	.068	<.001
Effect Sizes			
	Z	-.015	-.161
	r	-.015	-.160
	r^2	.0002	.026

TABLE 14. (Cont'd)

		Speed	Accuracy
Short-Term Memory	k	2	37
Significance Levels			
	Z	.063	-3.944
	p	.475	<.001
Effect Sizes			
	Z	.003	-.136
	r	.003	-.135
	r^2	.000008	.018
Cognitive	k	5	31
Significance Levels			
	Z	-.275	-6.314
	p	.392	<.001
Effect Sizes			
	Z	-.01	-.228
	r	-.01	-.224
	r^2	.0001	.050
Pattern Recognition	k	16	10
Significance Levels			
	Z	.959	4.314
	p	.169	<.001
Effect Sizes			
	Z	.028	.225
	r	.028	.221
	r^2	.0008	.049

When speed was the criterion, the effect of noise was negligible for most tasks. (However, note that in most cases the number of hypothesis tests were too few to provide reliable estimates.)

For accuracy, noise had a negative effect on performance for five of the six task types. The effect of noise was small to moderate for cognitive tasks ($r = -.224$), psychomotor tasks ($r = -.160$), and short-term memory tasks ($r = -.135$); these effects were also significant (p's $< .001$). For vigilance tasks, the effect of noise was negligible ($r = -.076$) and insignificant

(p = .208). For reaction tasks, there were too few studies within this category to provide a valid comparison. For one type of task, pattern recognition, noise improved performance accuracy; This effect was small to moderate (r = .221) and significant (p < .001).

Table 15 presents the five task types sensitive to degradation under noise, with corresponding mean r's representing the magnitude of effect of noise on performance accuracy. An asterisk (*) in a cell indicates that the effect of noise on performance accuracy differs significantly (p < .05) for those two task types.

The results in Table 15 provide an empirical basis to the oft-cited claims that noise effects vary by the type of task. In summary, we find no effect of noise on vigilance performance, consistent with the predictions of Coates and Alluisi (1975), and others. However, we find that psychomotor tasks are sensitive to noise effects, contrary to the claim (Cohen & Weinstein, 1981) that psychomotor tasks are likely to show little decrement to noise. Further, we find that cognitive tasks are particularly susceptible to degradation under noise (consistent with the claims of McCormick & Sanders (1982) and others).

TABLE 15. DIFFERENCES IN EFFECT SIZES BETWEEN TYPES OF TASKS

	Reaction r=-.464	Vigil. r=-.076	Psy/motor r=-.160	Memory r=-.135	Cognitive r=-.224
Reaction	---	*	*	*	*
Vigilance		---	ns.	*	*
Psy/motor			---	ns.	ns.
Memory				---	ns.
Cognitive					---

Summary

The goal of this analysis was to specify the effects of noise on performance accuracy, performance speed, and self-reported stress to provide practical and precise guidelines for manipulating noise. The results of this analysis are summarized in Table 16.

General Effect of Noise

Self-Report: Strong relationship between noise and self-reported stress.

Performance Speed: No simple overall effect between noise and performance speed.

TABLE 16. NOISE: SUMMARY OF OVERALL EFFECTS

	Self-Report	Speed	Accuracy
Significance Levels			
$Z_{significance}$	-15.317	.091	-7.229
p	< .001	.464	< .001
Effect Sizes			
Z_{Fisher}	-.631	.005	-0.14
r	-.558	.005	-0.14
r^2	.312	.00002	0.02

Performance Accuracy: Weak effect; noise slightly impairs performance accuracy.

Effect of Mode of Delivery

Self-Report: Greater perceived stress with headphones.

Performance Speed: No effect.

Performance Accuracy: Greater impairment of performance accuracy with speakers.

Effect of Intermittency

Self-Report: Greater perceived stress with noise bursts.

Performance Speed: Continuous noise impairs performance speed more than intermittent noise.

Performance Accuracy: No effect.

Effect of Decibel Level

Self-Report: Greater perceived stress with increased decibel level.

Performance Speed: Greater impairment with increased decibel level when noise is presented via speakers.

Performance Accuracy: Greater impairment with increased decibel level when noise is presented via speakers.

Effect of Noise Duration

Self-Report: Perceived stress decreases with increasing duration of noise.

Performance Speed: Increased impairment with longer duration when noise is presented in bursts.

Performance Accuracy: Increased impairment with longer duration when noise is presented continuously and via speakers.

Guidelines for Manipulating Noise

These results suggest that noise is a strong and effective means to impose perceived stress. To develop a realistic combat simulation which imparts the "feeling" of this stressor environment, noise should be included as a stressor.

However, noise has weaker effects on performance, particularly speed of performance. Our results support the contention that there is a "trade-off" between speed and accuracy under noise stress; individuals tend to make more errors under noise stress, yet maintain performance speed. Therefore, for a task in which effective performance is primarily determined by speed rather than accuracy (such as sorting large parts into a bin), we expect noise stress to have little effect. Furthermore, this type of task would be a poor choice as a laboratory task to assess the effects of noise stress.

Noise is shown to have weak, yet significant effects on performance accuracy. If the effective performance of a task is primarily determined by accuracy (such as repairing a defective module), we expect that noise will function as a weak yet significant stressor. Furthermore, we expect noise to have greater effects if the task is a cognitive versus a psychomotor or short-term memory task.

Table 17 provides further guidelines on manipulating noise. The correlation coefficient (r) is a useful index of magnitude of effect. In psychological research, levels of r are frequently characterized as small ($r = .1$), medium ($r = .3$), and large ($r = .5$), according to Cohen's (1977) guidelines for effect size. Table 17 provides a gauge of the noise level in decibels required to produce a small ($r = .1$), medium ($r = .3$), and large ($r = .5$) effect on self-reported stress and performance accuracy.

TABLE 17. MANIPULATION OF DECIBEL LEVEL TO ATTAIN SMALL, MEDIUM, AND LARGE LEVELS OF EFFECT

r	Decibel Level	
	Self-Report	Performance Accuracy
.1	81	76
.2	83	110
.3	86	145
.4	89	---
.5	92	---

Table 17 indicates that a minimum 81 dB noise is required to produce any discernable effect ($r = .1$) on self-reported stress. On average, individuals do not "feel" stressed at noise levels below 81 dB. Noise at 86 dB produces a medium or moderate effect on self-report, and a noise of 92 dB produces a large or strong effect.

For accuracy, a 76 dB noise is sufficient to impose a small or weak decrement on performance. However, to attain a medium or moderate effect, a noise of 145 dB is required. This level is outside the range of intensity that is likely to be manipulated in the laboratory (the loudest noise in our database was 115 dB), and reflects the relatively weaker effect of noise on accuracy versus self-report.

These results also suggest that the individual is much more likely to "feel" stressed before task performance is degraded to any significant degree. By implication, noise on the battlefield may cause more subjective stress than task degradation per se. If noise is more likely to make people feel bad than affect their performance, can the military researcher who is primarily concerned that combat personnel "get the task done," ignore the effects of noise stress? We argue this is not the case. High perceived stress may have repercussions on the battlefield (such as lowered motivation, quitting, or becoming a stress casualty) that would not be reflected in simple task performance data. Therefore, the fact that we find a strong effect of noise on self-reported stress implies that this factor should be addressed in the preparation and training of combat personnel.

There are several types of methods or tactics that the military forces undertakes to prepare personnel for combat: (a) indoctrination, (b) skills training, and (c) confidence drill. Indoctrination provides information on the various combat missions and environments, and increases understanding of and commitment to mission performance. Formal indoctrination usually

takes place in the classroom. Skills training provides the individual with exposure to the stress environment. This exposure allows an individual to experience task degradation stemming from the stressor environment, and either develop work-around procedures or adapt to the environment so that performance returns to an acceptable level. Confidence drill provides pre-exposure to the stressor environment to impart the "feeling" of the stress. A good confidence drill will allow individuals to experience the stressor environment, and develop positive expectations regarding their ability to perform under those conditions. Confidence drill and skills training for combat are usually accomplished in training exercises or simulations.

The present results suggest that we would manipulate noise differently for confidence drill versus skills training. If our purpose was to provide skills training in a noise environment, then our goal would be to degrade performance and train the individual to increase performance to an acceptable level. If our purpose was to provide confidence drill in a noise environment, then our goal would be to increase perceived stress, then allow the individual to habituate to the environment or perform tasks to build positive performance expectations.

Table 18 shows how we would differentially manipulate noise to affect self-report (perceived stress) versus to impair performance accuracy.

To achieve a strong effect of noise on self-reported stress requires a noise of 92 dB presented in bursts through headphones. To achieve the most effective manipulation of noise on performance accuracy requires a continuous noise of 110 dB presented in a free-field mode (through speakers).

TABLE 18. NOISE MANIPULATIONS FOR CONFIDENCE DRILL VERSUS SKILLS TRAINING

	Self-Report	Performance Accuracy
General Effects	Strong significant effect of noise on perceived stress	Weak significant effect of noise on performance accuracy
Mode of Delivery	Stronger effect with headphones	Stronger effect with speakers
Decibel Level	92 dB noise produces strong effect	110 dB noise produces weak-to-moderate effect
Intermittency	Stronger effect with noise bursts	Stronger effect with continuous noise
Duration	Weaker effect with increasing duration	Stronger effect with increasing duration

Studies Included in the Meta-Analysis

Study	Hyp.	Statistics	IN	DR	MD	BR	TK
Albery, 1988	SP	t(16) = .059 (-) [9]	90	6	1	1	3
	SP	t(16) = .824 (+) [9]	100	6	1	1	3
	SP	t(16) = .883 (+) [9]	100	6	1	1	3
	AC	t(16) = .418 (+) [9]	90	6	1	1	3
	AC	t(16) = .251 (+) [9]	100	6	1	1	3
	AC	t(16) = .167 (-) [9]	100	6	1	1	3
Bell, 1978	AC	F(1, 132) = 9.11 (-) [144]	95	6	0	0	3
Boggs & Simon, 1968	AC	F(1, 40) = .14 (-) [48]	92	10	0	0	1
Broadbent, 1957 Experiment 1	AC	t(12) = .07 (+) [16]	90	25	0	1	1
	AC	t(12) = 2.35 (-) [16]	100	25	0	1	1
	AC	t(12) = 2.42 (-) [16]	100	25	0	1	1
Broadbent, 1953	AC	Z = 1.96 (-) [18]	100	30	0	1	1
Burger & Arkin, 1980	SR	t(72) = 2.85 (-) [40]	90	17	1	0	5
	SR	t(72) = 2.27 (-) [40]	90	17	1	0	5
	SR	t(72) = 2.71 (-) [40]	90	17	1	0	5
	SR	t(72) = 4.51 (-) [40]	90	17	1	0	5
	AC	t(72) = .29 (-) [40]	90	17	1	0	5
	AC	t(72) = .53 (-) [40]	90	17	1	0	5
	AC	t(72) = .58 (-) [40]	90	17	1	0	5
	AC	t(72) = 5.9 (-) [40]	90	17	1	0	5
	SP	r(19) = .364 (+) [18]	80	4	0	0	4

Study	Hyp.	Statistics	IN	DR	MD	BR	TK
Cohen et al., 1974 Study 1	AC	X2(1) = .42 (-) [18]	80	4	0	0	4
Study 2	AC	F(1, 30) = 157.53 (-) [6]	100	33	0	0	5
Study 3	AC	t(42) = .15 (-) [16]	93	60	1	1	5
	AC	t(42) = .47 (+) [16]	93	30	1	0	5
	AC	t(42) = .29 (+) [16]	93	32	1	0	5
Conrad, 1973	AC	t(28) = .07 (-) [16]	93	5	1	1	5
	AC	t(28) = .21 (+) [16]	93	2.5	1	0	5
	AC	t(28) = .13 (+) [16]	93	2.6	1	0	5
Daee & Wilding, 1977 Experiment 1	AC	r(57) = .15 (+) [40]	75	5.3	1	1	4
	AC	r(57) = -.19 (-) [40]	85	5.3	1	1	4
	AC	r(57) = -.38 (-) [40]	85	5.3	1	1	4
Experiment 2	AC	r(76) = .125 (-) [80]	75	5.3	1	1	4
Experiment 3	AC	r(57) = .252 (+) [40]	75	5.3	1	1	4
	AC	r(57) = .213 (-) [40]	85	5.3	1	1	4
	AC	r(57) = .442 (-) [40]	85	5.3	1	1	4
Davies & Davies, 1975 Experiment 1	SP	t(72) = 1.693 (-) [40]	95	15	0	1	6
Davies & Hockey, 1966	AC	r(40) = .164 (-) [48]	95	32	0	1	6
Donnerstein & Wilson, 1976, Experiment 1	SR	r(36) = .563 (-) [40]	95	2	1	0	0
Eschenbrenner, 1971	AC	t(60) = .139 (-) [12]	90	6.7	1	0	3
	AC	t(60) = 3.07 (-) [12]	90	6.7	1	0	3
	AC	t(60) = 1.68 (-) [12]	70	6.7	1	0	3
	AC	t(60) = .64 (-) [6]	90	13	1	1	3
	AC	t(60) = 1.23 (-) [6]	90	13	1	1	3

Study	Hyp.	Statistics	IN	DR	MD	BR	TK
Eschenbrenner, 1971	AC	$t(60) = .59$ (-) [6]	70	13	1	1	3
Finkelman et al., 1977	AC	$F(1, 114) = 4.64$ (-) [8]	93	0.9	0	0	3
Finkelman et al., 1979	AC	$F(1, 198) = 7.506$ (-) [18]	90	1.1	1	0	4
Fowler & Wilding, 1979, Experiment 3	AC	$t(21) = 2.32$ (-) [16]	0.8	1	1	1	4
	AC	$t(21) = 4.34$ (-) [16]	0.8	1	1	1	4
	AC	$t(21) = 2.02$ (-) [16]	0.8	1	1	1	4
Gardinier, 1971	AC	$F(1, 48) = .38$ (+) [12]	95	4	0	1	3
Gardner, 1978	AC	$Z = .39$ (-) [30]	100	24	1	0	5
	SP	$F(1, 56) = 7.46$ (-) [30]	100	24	1	0	5
	SP	$F(1, 56) = 2.86$ (+) [30]	100	24	1	0	5
	AC	$Z = .09$ (-) [30]	100	24	1	0	5
Hamilton et al., 1972 Experiment 2	AC	$F(1, 96) = 1.57$ (+) [100]	85	2.7	0	1	4
Hamilton & Copeman, 1970	AC	$F(1, 55) = .33$ (-) [12]	100	30	0	1	3
Harris, 1970	AC	$F(1, 18) = 15.5$ (-) [20]	112	12	0	0	3
Harris & Filson, 1971	AC	$r(23) = .233$ (-) [70]	105	36	1	1	5
Hartley, 1973	AC	$t(36) = 8.36$ (-) [13]	100	40	0	1	1
Hartley, 1974 Experiment 1	AC	$r(68) = .341$ (-) [36]	95	27	0	0	1
	AC	$r(68) = .479$ (-) [36]	95	40	0	0	1
Experiment 2	AC	$F(1, 115) = 10.88$ (-) [16]	95	40	0	0	1
Hartley, 1976	AC	$r(15) = .560$ (-) [16]	95	40	0	1	1
	AC	$r(15) = .627$ (-) [16]	95	40	1	1	1
Hartley, 1981	AC	$r(17) = .394$ (-) [18]	95	33	0	1	3
Heimstra, 1972 Experiment 4	AC	$t(57) = 5.39$ (+) [20]	85	18	1	0	2

2

Study	Hyp.	Statistics	IN	DR	MD	BR	TK
Heimstra, 1972	AC	t(57) = 2.15	85	42	1	0	
Experiment 4		(+) [20]					
	AC	t(57) = .88	85	60	1	1	2
		(+) [20]					
	AC	F(1, 27) = 6.858	100	10	1	1	3
Exper. 5, Study 1		(+) [30]					
	AC	F(1, 17) = 1.049	100	15	1	1	3
Exper. 5, Study 2		(+) [20]					
	AC	X2(1) = .413	80	0.3	0	1	4
Hockey & Hamilton,		(-) [68]					
1970	AC	r(43) = .096	78	12	1	1	6
Houston, 1968		(-) [45]					
	AC	F(1, 18) = .047	113	105	0	1	2
Jerison, 1957		(-) [20]					
	AC	r(14) = .578	80	30	0	1	5
Jones & Broadbent,		(-) [16]					
1979	AC	r(26) = .063	85	120	0	1	2
Jones et al., 1979		(-) [14]					
Experiment 1	AC	r(26) = .272	85	120	0	1	2
Experiment 2		(-) [14]					
	AC	F(1, 16) = .15	85	120	0	1	2
Experiment 3		(-) [18]					
	AC	F(1, 70) = 30.88	69	8.8	0	1	1
Kallman & Isaac, 1977		(-) [12]					
	AC	t(56) = 1.97	64.5	40	0	1	2
Kirk & Hecht, 1963		(+) [30]					
	AC	F(1, 48) = .11	95	4	0	1	3
Lewis, 1971		(+) [12]					
	AC	r(44) = .409	105	30	0	1	3
Loeb & Jones,		(-) [48]					
1978	SR	F(1, 31) = 106.3	105	15	1	0	5
Lovallo & Pishkin,		(-) [80]					
1980	SR	F(1, 68) = 144.19	105	30	1	0	5
		(-) [80]					
	AC	t(34) = .26	105	15	1	0	5
		(-) [80]					
	AC	r(6) = .431	70	120	0	1	5
Mech, 1953		(-) [60]					
	SP	F(1, 22) = 1.783	95	6.1	1	1	4
Millar, 1979		(-) [24]					
	AC	Z = .35	97	4.4	0	0	4
Moran & Loeb, 1977		(+) [80]					
Experiment 1	AC	Z = 5.18	97	14	0	1	4
		(+) [80]					
	AC	Z = 4.47	97	14	0	1	5
Experiment 2		(+) [48]					
	AC	t(40) = .31	75	9	0	0	4

Study	Hyp.	Statistics	IN	DR	MD	BR	TK
O'Malley & Poplawksy,		(+) [22]					
1971	AC	t(40) = 1.20	85	9	0	0	4
		(-) [22]					
	AC	t(40) = 1.42	100	9	0	0	4
		(-) [22]					
	AC	t(40) = 1.51	85	9	0	0	4
		(-) [22]					
	AC	t(40) = 1.73	100	9	0	0	4
		(-) [22]					
	AC	t(40) = .22	100	9	0	0	4
		(-) [22]					
	SR	r(25) = .503	94	14	0	0	5
Percival & Loeb,		(-) [42]					
1980, Experiment 1	AC	t(10) = .12	115	4	1	0	3
Plutchik, 1961		(+) [6]					
	AC	t(36) = 5.08	108	3.8	0	0	5
Reim, Glass, & Singer,		(-) [20]					
1971	AC	t(48) = 3.03	96	9.3	0	0	4
Salame & Wittersheim,		(-) [20]					
1978	AC	t(48) = 3.83	96	7.5	0	0	4
		(-) [20]					
	AC	t(48) = 1.54	96	1.8	0	0	4
		(-) [20]					
	AC	X2(1) = .87	110	21	1	1	5
Samuel, 1963		(+) [40]					
	SR	t(55) = 6.37	94	18	0	1	5
Sherrod et al., 1977		(-) [24]					
	SR	t(55) = 5.27	94	18	0	1	5
		(-) [24]					
	SR	t(55) = 5.34	94	18	0	1	5
		(-) [24]					
	SR	t(55) = 3.88	94	18	0	1	5
		(-) [24]					
	AC	t(55) = 2.08	94	18	0	1	5
		(-) [24]					
	AC	t(55) = 3.47	94	18	0	1	5
		(-) [24]					
	AC	t(55) = 4.39	94	18	0	1	5
		(-) [24]					
	AC	t(55) = 6.01	94	18	0	1	5
		(-) [24]					
Simpson et al., 1974	AC	t(14) = 2.916	80	15	1	1	3
		(-) [16]					
Smith, 1982	AC	t(41) = .74	85	5	0	1	4
Experiment 1		(-) [45]					
Experiment 2	AC	t(36) = .49	85	5	0	1	4
		(+) [40]					

Study	Hyp.	Statistics	IN	DR	MD	BR	TK
Smith and Broadbent, 1980, Experiment 1	AC	$F(1, 18) = .006$ (-) [20]	85	8	0	1	6
Experiment 2	AC	$F(1, 30) = .159$ (+) [32]	85	8	0	1	6
Smith and Broadbent 1981, Experiment 1	AC	$F(1, 16) = 1.12$ (+) [20]	85	3	0	1	5
Experiment 2	SP	$F(1, 20) = .086$ (-) [12]	85	3.3	0	1	1
Experiment 3	SP	$F(1, 10) = 1.02$ (-) [12]	85	3.3	0	1	1
Smith et al., 1981 Experiment 1	AC	$F(1, 16) = 1.01$ (-) [18]	80	13	0	1	4
Experiment 2	AC	$F(1, 21) = .043$ (+) [25]	80	13	0	1	4
Experiment 3	AC	$F(1, 16) = 5.86$ (-) [20]	85	13	0	1	4
Experiment 4	AC	$F(1, 19) = .08$ (-) [23]	85	13	0	1	4
Experiment 5	AC	$F(1, 14) = 1.79$ (-) [18]	85	13	0	1	4
Theologus, Wheaton, & Fleishman, 1974	SP	$r(143) = .216$ (-) [20]	85	43	1	0	3
	AC	$p = .50$ [20]	85	43	1	0	3
Von Wright & Vauras, 1980, Experiment 1	SP	$F(1, 28) = 7.03$ (+) [32]	95	5.1	1	0	5
	AC	$p = .02$ (-) [30]	95	5.6	1	0	4
Experiment 2	AC	$t(36) = 3.28$ (-) [40]	95	3.5	1	0	4
Experiment 3	AC	$F(1, 28) = 9.14$ (-) [32]	95	5.1	1	0	5
Warner & Heimstra, 1971	SP	$t(63) = 3.11$ (-) [22]	100	4.8	1	0	6
	SP	$t(63) = 1.33$ (+) [22]	100	11	1	0	6
	SP	$t(63) = .216$ (+) [22]	100	16	1	1	6
	AC	$Z = 1.013$ (+) [22]	100	4.8	1	0	6
	AC	$Z = .444$ (+) [22]	100	11	1	0	6
	AC	$Z = 1.013$ (+) [22]	100	16	1	1	6
Warner & Heimstra, 1972	SP	$t(479) = 1.074$ (-) [20]	80	48	1	1	6

Study	Hyp.	Statistics	IN	DR	MD	BR	TK
Warner & Heimstra, 1972	SP	t(479) = .392 (+) [20]	90	48	1	1	6
	SP	t(479) = .102 (+) [20]	100	48	1	1	6
	SP	t(479) = 1.47 (+) [20]	90	48	1	1	6
	SP	t(479) = 1.175 (-) [20]	100	48	1	1	6
	SP	t(479) = .290 (+) [20]	100	48	1	1	6
Warner & Heimstra, 1973	SP	t(57) = .148 (-) [20]	80	9.6	1	0	6
	SP	t(57) = 1.112 (-) [20]	90	9.6	1	0	6
	SP	t(57) = 2.964 (+) [20]	100	9.6	1	0	6
	SP	t(57) = .963 (-) [20]	90	9.6	1	0	6
	SP	t(57) = 3.11 (+) [20]	100	9.6	1	0	6
	SP	t(57) = 4.076 (+) [20]	100	9.6	1	0	6
Weinstein, 1974	SP	t(31) = .12 (+) [33]	68	14	0	0	5
	AC	t(31) = 2.86 (-) [33]	68	14	0	0	5
Weinstein, 1977	AC	F(1, 27) = 10 (-) [29]	68	6.6	0	0	5
Wilding et al., 1982 Experiment 1	AC	t(96) = 3.42 (+) [40]	75	-	1	1	4
	AC	t(96) = 2.56 (+) [40]	85	-	1	1	4
	AC	t(96) = .85 (-) [40]	85	-	1	1	4
	AC	F(1, 36) = .56 (-) [40]	85	-	1	1	4
Wohlwill et al., 1976	SR	F(1, 77) = 4.96 (-) [80]	80	30	0	1	5
	AC	F(1, 38) = .33 (-) [80]	80	30	0	1	5
Woodhead, 1964	AC	X2(1) = 2.99 (-) [42]	100	2	0	0	4
	AC	X2(1) = .16 (-) [42]	100	2	0	0	4
Wright & Nurmi, 1979	SP	F(1, 30) = 5.88 (-) [32]	95	1.6	1	1	5

Note:

Hyp.:	Hypothesis. AC = accuracy; SR = self-report; SP = Speed
Statistics:	(+) indicates that noise improved accuracy or speed, or led to a more favorable self report (-) indicates that noise led to a decrement in accuracy or speed, or to a more negative self-report Numbers in brackets indicate sample size.
IN:	Intensity. Numbers represent decibel level of noise.
DR:	Duration of noise in seconds.
MD:	Mode of delivery. 1 = delivery of noise via headphones; 0 = delivery of noise via speakers
BR:	Bursts. 1 = continuous noise; 0 = noise in bursts.
TK:	Type of task. 1 = reaction; 2 = vigilance; 3 = psychomotor; 4 = short-term memory; 5 = cognitive; 6 = pattern recognition

IV. TIME PRESSURE

Introduction

Common sense suggests that imposing time stress or time pressure will result in detrimental effects on task performance. For example, the high speed offensive operations and the high rate of sorties that will characterize the future battlefield are likely to have a significant impact on individual performance effectiveness. It is reasonable to expect that those who have experience performing their missions under time stress will be less vulnerable to performance degradation under the surge of combat. Yet, how is this exposure to be provided? How should time pressure be introduced? What degree of time pressure is necessary to impact performance? The following analysis examines the effects of time pressure on human performance. This meta-analysis will examine the effect of time pressure on performance speed and accuracy, and identify factors that moderate this relationship.

Nature and Theory of Time Pressure Effects

Research suggests that time pressure degrades performance because of the cognitive demands, or information overload, imposed by the requirement to process a given amount of information in a limited amount of time (Wright, 1974). Faced with conditions of time pressure, individuals may resort to several types of strategies to reduce the information overload. The first strategy, acceleration, refers to the process whereby the individual increases information integration to "match" the speed at which information is presented. This strategy assumes the task performer is processing information at some suboptimal rate initially and is thus able to increase processing activity in order to reduce the impact of time stress. It is unlikely that individuals performing complex tasks in combat will be operating at this suboptimal level to begin with, therefore, this strategy may have limited application for our current interests.

The second type of strategy involves a change or adjustment in information processing strategy. Under time pressure, individuals may alter the means by which they process information. For example, in evaluating each available alternative sequentially before attempting a task solution, an individual may switch to a strategy whereby all alternatives are considered according to a specific criteria prior to decision-making. These adjustments in strategy, although undertaken to reduce time stress, may lead to poorer performance (as when an inappropriate strategy is adopted).

A third strategy, filtration, refers to the general tendency for individuals to restrict information processing when they are under stress. By filtering or reducing the amount of information to be processed, the individual may reduce the overload imposed

by time pressure. However, this restriction of environmental information may have detrimental effects on task performance as attention to task-relevant information is also restricted.

Moderators

The effect of time pressure on performance may be moderated by several factors, including the type of manipulation used to induce time pressure, whether or not urging or deadlines were used, the magnitude of the time pressure, and the type of task used.

Type of Manipulation. Studies vary in the type of manipulation of time pressure they use. Some investigators have induced time pressure by simply making a statement such as, "You must hurry" in the preliminary instructions to subjects. For example, in a study of the effects of time pressure on problem solving, Goh and Farley (1977) introduced time stress by telling experimental subjects to work as quickly as they could. These cases will be referred to as "categorical" manipulations of time pressure (i.e., the manipulations are either "stressed" or "unstressed"). Other investigators induced time pressure by allotting little time for completion of the experimental task. For example, subjects might be given only 20 minutes to complete a task that would normally require 40 minutes. In one condition of Huchingson (1973), subjects were required to perform a task at 60% of a previous self-paced time-to-completion criterion. These manipulations of time pressure on a continuous metric will be referred to as "continuous" manipulations.

Urging. In some cases, the time pressure manipulation was continuous, yet the experimenter also urged the subjects to hurry, as with categorical manipulations. For example, Link (1971) provided subjects with feedback (i.e., "too slow") when time deadlines were exceeded. A variable called "urging" was created to allow for comparisons between such studies and those with continuous manipulations with no such urging.

Deadline. Another aspect of the manipulation of time pressure is whether or not subjects were given a deadline. In some studies, subjects were simply interrupted when their time on the experimental task was up. In others, the subjects were given a deadline: they were either told up front how much time they would have to complete the task and/or at some point(s) during task performance they were informed of the time remaining to complete the task. For example, Farmer, Hunter, and Belyavin (1984) provided subjects with a continuous display indicating the proportion of the time limit that had expired. A variable called "deadline" was created to allow comparisons between studies which imposed deadlines and those which did not.

Research on goal-setting (Locke, 1968) has shown that specific goals result in higher performance than no goals or

vague, generalized goals such as "Do your best" or "Work as quickly as you can." On the basis of these results, higher performance would be expected when specific goals, such as deadlines, are communicated up front. For example, it may be a more effective manipulation to state the following before the subject begins working on the task, "You will be given 60 seconds to complete the task" rather than interrupting when the allotted time is up or simply encouraging the subject to hurry.

Magnitude. One important moderator that can be reliably derived from studies of the effects of time pressure is the intensity or magnitude of the time pressure under which operators must perform. The studies represented in this integration have operationalized time pressure in various ways (e.g., duration between stimulus presentations or percent of baseline self-paced time allotted for task performance, etc.). For example, an investigator may establish a baseline time for performance of a specific task at 20 seconds, then introduce time pressure by setting the time limit at 10 seconds. Each hypothesis test comparing a condition of higher time pressure with lower time pressure can be represented by a gauge of the relative difference in time pressure between those two conditions. For continuous manipulations, we may define this index of magnitude of time pressure as:

$$Mag_{CONT} = \text{longer time period} / (\text{longer period} + \text{shorter period})$$

For example, if one study examines the effects of a 15-second period on performance versus a 10-second period, the index is calculated as: $Mag_{CONT} = 15/(15 + 10)$, or .6. If a second test examines the effects of a 15-second period versus a 5-second period, the index is calculated as $Mag_{CONT} = 15/(15 + 5)$, or .75. Therefore, the larger the magnitude index, the greater or more extreme the manipulation of time pressure.

Whereas the operationalization of magnitude for continuous manipulations was derived from the mechanics of that manipulation (which Mullen (1989) has called a post-hoc theoretical indicator), the magnitude for categorical manipulations of time pressure was derived from subjective ratings of the intensity of the time pressure for high-pressure and low-pressure conditions. Each manipulation was rated on a scale of one to ten, with one = no time pressure and ten = most time pressure. The average rating for each condition will be referred to as the "judged pressure." The correlation between these subjective judgments was remarkably high ($r = .838$). The Spearman-Brown effective reliability for these judgments was .912. For categorical manipulations, the index of magnitude of time pressure may be defined as:

Mag_{CAT} = judged pressure for high pressure / (judged pressure for high pressure + judged pressure for low pressure)

For example, if the judged pressure for the high pressure condition for a particular study was ten and the judged pressure for the low pressure condition was one, the index is calculated as: $Mag_{CAT} = 10 / (10 + 1)$, or .909. If the judged pressure for the high pressure condition was four and the judged pressure for the low pressure condition was one, the index is calculated as: $Mag_{CAT} = 2 / (2 + 1)$, or .667. Therefore, as with the magnitude index for continuous manipulations, the larger the magnitude index for categorical manipulations, the greater or more extreme the manipulation of time pressure.

Type of Task. Broadbent (1971) reported that at high levels of arousal, there is a "funneling of attention" on the task. When arousal is high, attention will be focused on what the subject perceives to be the most important aspects of a task or the most probable source of information. Performance declines when relevant task information is missed due to this process. For some tasks, proficient performance requires attending to only a few simple cues. Performance on such tasks may improve with an arousal-induced narrowing of attention, because distracting cues are no longer noticed. On the other hand, some tasks demand attending to a wide range of cues. Any increase in arousal and corresponding restriction of cues may result in poorer performance. Because the effect of time pressure may vary by type of task, we will analyze separately the effects of time pressure for pattern recognition, reaction time, vigilance, psychomotor, short-term memory, and cognitive tasks.

Procedure

Consistent with the procedure specified in Chapter II of this report, an exhaustive search was conducted to identify studies on time pressure and performance utilizing several specific search techniques. Computer-based abstracting services were used to search the Defense Technical Information Center (DTIC) and PSYCHINFO databases. Using the ancestry approach, we searched the bibliographies and reference sections of available reports and articles to identify previous relevant studies. Using the descendency approach, we used indexing sources (such as the Social Sciences Citation Index) to locate relevant studies cited in earlier references. In addition, we manually searched major technical journals to identify relevant articles.

Studies were included in the meta-analysis if they reported the effect of a relatively high time pressure versus that of a relatively low time pressure on performance (speed or accuracy). Studies were eliminated from consideration if the basic statistical information required for analysis was not retrievable.

We analyzed the effects of time pressure separately for two outcome measures. The first measure analyzed was performance accuracy (i.e., number of errors). The studies in the analysis yielded a total of 87 hypothesis tests for the effects of time pressure on accuracy. The second outcome measure analyzed was speed of performance. The studies in the analysis yielded 79 hypothesis tests for the effects of time pressure on speed. The hypothesis tests included in this meta-analysis are presented at the end of the chapter.

Results

General Effects. Table 19 presents the results of an analysis of 79 hypothesis tests of the effect of time pressure on performance speed. These results indicate that there is a moderate ($r = .304$) and significant ($p < .001$) tendency for time pressure to enhance speed of performance.

TABLE 19. GENERAL COMBINATIONS OF SIGNIFICANCE LEVELS AND EFFECT SIZES: TIME PRESSURE AND PERFORMANCE SPEED

79 Hypothesis Test (weighted by sample size)

Combination of Significance Levels
Z for combination = 10.355
Associated one-tailed p = < .001

Fail-safe number (p = .05) = 25,674

Combination of Effect Sizes
Mean Fisher's Z = .314
Mean r = .304
Mean r^2 = .092

Table 20 presents results of the analysis of 87 hypothesis tests of the effect of time pressure on performance accuracy. As might be expected, performance accuracy suffered when time pressure was imposed. This tendency was slight ($r = -.095$), yet significant ($p < .001$).

Type of Manipulation. Table 21 presents the results of separate analyses for hypothesis tests in which the time pressure manipulation was categorical, and for those in which it was continuous.

For both speed and accuracy, there is a significant effect of manipulation type on effects of time pressure. That is, the

TABLE 20. GENERAL COMBINATIONS OF SIGNIFICANCE LEVELS AND EFFECT SIZES: TIME PRESSURE AND PERFORMANCE ACCURACY

87 Hypothesis Test (weighted by sample size)

Combination of Significance Levels
Z for combination = 3.439
Associated one-tailed p = < .001

Fail-safe number (p = .05) = 12,346

Combination of Effect Sizes
Mean Fisher's Z = -.095
Mean r = -.095
Mean r^2 = .009

TABLE 21. EFFECTS OF TIME PRESSURE WITHIN TYPE OF MANIPULATION

	Speed	Accuracy
Continuous		
Significance Levels		
$Z_{significance}$	24.000	17.042
p	<.001	<.001
Effect Sizes		
Z_{FISHER}	.633	-.489
r	.560	-.453
r^2	.313	.206
Categorical		
Significance Levels		
$Z_{significance}$	5.710	1.634
p	< .001	< .051
Effect Sizes		
Z_{FISHER}	.193	.054
r	.191	.054
r^2	.036	.003
Focused Comparison		
Z	2.439	4.157
p	.007	< .001

type of manipulation of time pressure (categorical or continuous) is predictive of study outcomes. For speed, Z for comparison = 2.439, $p = .007$. For accuracy, Z for comparison = 4.157, $p < .001$.

Due to this overarching effect, all subsequent analyses will rely upon type of manipulation as a critical blocking variable. Continuous manipulations of time pressure produce much stronger effects, both in terms of enhancement of speed ($r = .560$ vs. $r = .191$ for categorical manipulations) and degradation of performance accuracy. With continuous manipulations, there is a strong ($r = .560$) and significant ($p < .001$) increase in speed. When categorical manipulations are used, there is a small-to-moderate ($r = .191$) and significant ($p < .001$) increase in speed.

For categorical manipulations, there is a slight ($r = .054$), yet significant ($p = .051$) enhancement of accuracy. Conversely, for continuous manipulations of time pressure, there is a moderate-to-strong ($r = -.453$) and significant ($p < .001$) impairment of performance accuracy.

Magnitude. Table 22 presents correlations between magnitude and effect sizes. It also shows focused comparisons of effect sizes for magnitude for hypothesis tests in which the time pressure manipulation was categorical, and for those in which it was continuous.

For both speed and accuracy, there is an interaction between magnitude of time pressure and type of manipulation of time

TABLE 22. EFFECTS OF MAGNITUDE WITHIN TYPE OF MANIPULATION

	Speed	Accuracy
Continuous		
r	.520	-.486
Focused Comparisons		
Z	2.100	1.459
p	.018	.072
Categorical		
r	.018	-.046
Focused Comparisons		
Z	.207	.913
p	.418	.181

pressure. Stronger magnitudes of continuous manipulations yield stronger enhancements of speed ($r = .520$, Z for comparison = 2.100, $p = .018$). However, there is no effect of magnitude of time pressure on speed for categorical manipulations ($r = .018$, Z for comparison = .207, $p = .418$). Stronger magnitudes of continuous manipulations yield stronger impairments in accuracy ($r = -.486$, Z for comparison = 1.459, $p = .072$). However, there is no effect of magnitude of time pressure on accuracy for categorical manipulations ($r = -.046$, Z for comparison = .913, $p = .181$).

Urging. Table 23 presents correlations between urging and effect size for hypothesis tests where the time pressure manipulation was continuous, as well as the focused comparison of effect sizes for urging with continuous manipulations. More urging with continuous manipulations of time pressure yields stronger impairments of accuracy ($r = -.482$, $p = .037$). Naturally, there was no variation in urging among the categorical manipulations, because, by definition, these all involved urging. There was a strong ($r = .548$) and significant ($p = .003$) effect in the direction of urging resulting in a stronger enhancement of speed.

TABLE 23. EFFECTS OF URGING FOR CONTINUOUS MANIPULATIONS

	Speed	Accuracy
r	.548	-.482
Focused Comparison		
Z	2.784	1.780
p	.003	.037

Table 24 presents the general combinations for hypothesis tests blocked into three groups: (1) those with continuous manipulations where the investigator urged the subjects to hurry; (2) those with continuous manipulations where the investigator did not urge subjects to hurry; and (3) those with categorical manipulations where by definition, the investigator urged the subjects to hurry.

Time pressure was generally associated with an enhancement in speed of performance. The strongest improvements in performance speed due to time pressure occurred with continuous manipulations with urging. This effect was of strong magnitude (.867) and significant ($p < .001$). The next strongest effect of time pressure was for continuous manipulations with no urging. This effect was of moderate-to-strong magnitude ($r = .412$) and significant ($p < .001$). Finally, the smallest enhancement of

speed was in the group of categorical manipulations. Here, the effect was of small-to-moderate magnitude ($r = .191$) and significant ($p < .001$). In summary, although speed is enhanced with categorical manipulations, it is improved to a significantly greater extent with continuous manipulations with no urging, and still more with continuous manipulations with urging.

TABLE 24. EFFECTS OF TIME PRESSURE FOR CONTINUOUS MANIPULATIONS WITH URGING, CONTINUOUS MANIPULATIONS WITHOUT URGING, AND CATEGORICAL MANIPULATIONS

	Speed	Accuracy
Continuous/Urging		
Significance Levels		
$Z_{significance}$	-17.427	9.645
p	< .001	< .001
Effect Sizes		
Z_{FISHER}	1.321	-.809
r	.867	-.669
r^2	.752	.447
Continuous/No Urging		
Significance Levels		
$Z_{significance}$	17.203	-15.526
p	.001	< .001
Effect Sizes		
Z_{FISHER}	.438	-.344
r	.412	-.331
r^2	.170	.109
Categorical/Urging		
Significance Levels		
$Z_{significance}$	5.710	1.634
p	<.001	.051
Effect Sizes		
Z_{FISHER}	.193	.054
r	.191	.054
r^2	.036	.003

Time pressure was associated with a decline in accuracy for both of the continuous groups. The strongest impairments in performance accuracy due to time pressure occurred with continuous manipulations with urging. This effect was of strong magnitude ($r = -.669$) and significant ($p < .001$). Continuous manipulations of time pressure with no urging also resulted in impaired accuracy. Here, the effect was moderate ($r = -.331$) and significant ($p < .001$). It is important to note that within continuous manipulations of time pressure, a greater decrement in accuracy occurs with urging than without urging. In contrast to the results for continuous manipulations, categorical manipulations actually resulted in a marginally significant ($p = .051$) accuracy improvement, although it is of negligible magnitude ($r = .054$).

Deadline. Table 25 presents the general effects for all four combinations of type of time pressure manipulation and deadline. For all combinations, speed of performance was enhanced. The greatest improvement occurred with continuous manipulations with a deadline. This effect was very strong ($r = .619$) and significant ($p < .001$). Somewhat less enhancement occurred with continuous manipulations without a deadline ($r = .488$, $p < .001$). Both groups of categorical manipulations yielded less improvement in speed than the two continuous manipulations. In contrast to the results for continuous manipulations, with categorical manipulations, no deadline led to faster performance than setting deadlines. The effect of time pressure on speed was moderate in the cases without deadlines ($r = .319$, $p = .03$) and small-to-moderate with deadlines ($r = .184$, $p < .001$).

Accuracy was impaired by time pressure with continuous manipulations. The extent of impairment was about the same whether a deadline was imposed ($r = -.464$) or not ($r = -.443$). In both cases the effect was moderate-to-strong and significant ($p < .001$). Accuracy was actually improved by time pressure when the manipulations were categorical. When no deadline was set, the improvement was of moderate-to-strong magnitude ($r = .399$) and significant ($p = .019$). When a deadline was set, the improvement was negligible ($r = .041$) and nonsignificant ($p = .085$).

For both speed and accuracy, there is an interaction between deadline and type of manipulation of time pressure. When speed is the criterion, imposing a deadline yields stronger enhancements of speed for continuous manipulations. However, deadlines result in slower performance for categorical manipulations.

When the criterion is accuracy, administering a deadline does not make a significant difference with continuous

TABLE 25. EFFECTS OF TIME PRESSURE WITHIN MANIPULATION TYPES AND DEADLINE

	Speed	Accuracy
Continuous/Deadline		
Significance Levels		
$Z_{significance}$	15.043	14.405
p	< .001	< .001
Effect Sizes		
Z_{FISHER}	.724	-.503
r	.619	-.464
Continuous/No Deadline		
Significance Levels		
$Z_{significance}$	23.584	10.249
p	<.001	< .001
Effect Sizes		
Z_{FISHER}	.534	-.476
r	.488	-.443
Categorical/Deadline		
Significance Levels		
$Z_{significance}$	5.487	1.370
p	<.001	.085
Effect Sizes		
Z_{FISHER}	.186	.041
r	.184	.041
Categorical/ No Deadline		
Significance Levels		
$Z_{significance}$	1.889	2.079
p	.030	.019
Effect Sizes		
Z_{FISHER}	.330	.422
r	.319	.399

manipulations. With categorical manipulations, accuracy is impaired by setting a deadline.

Type of Task. Table 26 presents the results of separate combinations of significance levels and effect sizes for hypothesis tests involving perceptual, reaction, vigilance, psychomotor, short-term memory, and cognitive tasks.

Time pressure had the general effect of impairing accuracy and enhancing speed. Among the six task types, time pressure had the most deleterious effects on accuracy in pattern recognition ($r = -.669$) and reaction tasks ($r = -.347$). Interestingly, the greatest enhancement of speed was also for these two types of task ($r = .867$ for pattern recognition, $r = .497$ for reaction).

TABLE 26. EFFECTS OF TIME PRESSURE WITHIN TYPE OF TASK

	Accuracy	Speed
Reaction		
k	49	49
Significance Levels		
$Z_{significance}$	-16.410	23.813
p	< .001	< .001
Effect Sizes		
Z_{FISHER}	-.362	.545
r	-.347	.497
r^2	.120	.247
Vigilance		
k	2	0
Significance Levels		
$Z_{significance}$	-1.732	---
p	.416	---
Effect Sizes		
Z_{FISHER}	-.881	---
r	-.707	---
r^2	.500	---

TABLE 26. (Continued)

Psychomotor		
Significance Levels		
$Z_{significance}$	-2.449	3.624
p	.007	.001
Effect Sizes		
$Z_{r\,FISHER}$	-.078	.171
r	-.078	.169
r^2	.006	.029
Short-Term Memory		
k	3	0
Significance Levels		
$Z_{significance}$	-1.214	---
p	-.881	---
Effect Sizes		
$Z_{r\,FISHER}$	-.080	---
r	-.080	---
r^2	.006	---
Cognitive		
k	15	12
Significance Levels		
$Z_{significance}$	3.66	5.45
p	<.001	<.001
Effect Sizes		
$Z_{r\,FISHER}$	.149	.227
r	.148	.224
r^2	.022	.050

TABLE 26. (Concluded)

Pattern Recognition		
k	10	9
Significance Levels		
$Z_{significance}$	-9.64	17.427
p	<.001	<.001
Effect Sizes		
$Z_{r\,FISHER}$	-.809	1.32
r	-.669	.867
r^2	.447	.752

Summary

One goal of this meta-analysis is to specify the effects of time pressure on performance, in order to provide the stress researcher with practical guidelines for manipulating time pressure. The results of this analysis are summarized below and in Table 27.

TABLE 27. TIME PRESSURE: BASIC EFFECTS

	Speed	Accuracy
Significance Levels		
$Z_{significance}$	10.355	3.439
p	< .001	< .001
Effect Sizes		
$Z_{r\,FISHER}$	.314	-.095
r	.304	-.095
r^2	.092	.009

General Effect of Time Pressure

Performance Accuracy: Weak, yet significant effect of time pressure to degrade performance accuracy.

Performance Speed: Moderate and significant effect of time pressure to enhance performance speed.

Effect of Type of Manipulation

Performance Accuracy: Moderate-to-strong impairment of performance accuracy with continuous manipulations; slight enhancement of performance accuracy with categorical manipulations.

Performance Speed: Strong enhancement of performance speed with continuous manipulations; weak enhancement of speed with categorical manipulations.

Effect of Magnitude of Time Pressure

Performance Accuracy: For continuous manipulations, the greater the magritude of time pressure, the greater the impairment of accuracy.

Performance Speed: For continuous manipulations, the greater the magnitude of time pressure, the greater the enhancement of speed.

Effect of Urging

Performance Accuracy: For continuous manipulations, urging resulted in greater impairment of accuracy.

Performance Speed: For continuous manipulations, urging resulted in greater enhancements of speed.

Effect of Deadline

Performance Accuracy: For categorical manipulations, deadlines resulted in greater impairment of accuracy.

Performance Speed: For continuous manipulations, deadlines resulted in enhanced speed. For categorical manipulations, deadlines led to slower performance.

Effect of Type of Task

Performance Accuracy: Time pressure tended to impair accuracy for most task types. The task types most susceptible to this negative effect were pattern recognition and reaction tasks.

Performance Speed: Time pressure increased the speed of performance for all tasks. These effects were most profound for pattern recognition and reaction tasks.

Guidelines for Manipulating Time Pressure

First, we know that as a stress manipulation, time pressure has significant and strong effects on speed and quality of performance. Second, we know that the effects of time pressure on speed and accuracy are straight, linear functions. At least within the considerable range represented by these studies, there is no apparent asymptote of the metric of time pressure, beyond which further increases have no effect. This information is important in terms of providing specifications to the training system designer; knowing that the effects of time pressure are linear provides critical information concerning how this variable can be effectively manipulated.

Moreover, these linear effects of time pressure on speed and on accuracy are quite different. Although time pressure influenced both speed and accuracy, the effects on speed were more dramatic than the effects on accuracy. Thus, under a given increase in time pressure, operator speed will increase at a greater rate than operator accuracy will decrease. This trend may have implications for the performance and training of different tasks that require differing degrees of speed and accuracy. For example, consider a specific task (such as replacing a particular equipment component) in which effective performance has been estimated to be more determined by speed (75% speed) and less determined by accuracy (25%). Using the formula derived from this analysis, we may identify the exact percentage of time pressure that maximizes performance speed without degrading performance accuracy to the point that it significantly impacts the task.

In summary, time pressure impairs accuracy and enhances speed. This effect is stronger with continuous manipulations of time pressure than with categorical manipulations. The magnitude of the manipulation of time pressure exerts an effect on performance, but only for continuous manipulations. With continuous manipulations, urging also increased accuracy and enhanced speed of performance. Finally, the use of deadlines only decreased accuracy for categorical manipulations.

These data reflect a similar effect of time pressure on performance that we observed with noise: a tradeoff between speed and accuracy. Under time stress, individuals are able to maintain (or in the case of time pressure, enhance) the pace of performance, but at a cost in performance accuracy. Because of the nature of the time pressure manipulation (i.e., the primary goal is to work faster), we see a stronger effect of time pressure on enhancing performance speed, and a weaker effect of time pressure on degrading accuracy. However, with continuous manipulations of time pressure, we find that the effects of time pressure on accuracy ($r = -.489$) and on speed ($r = .560$) are substantial.

Table 28 provides specific guidelines for manipulating time pressure. It also provides a gauge of the magnitude of time pressure required to produce a small ($r = .1$), medium ($r = .3$) and large ($r = .5$) effect on performance speed and performance accuracy.

TABLE 28. MANIPULATION OF MAGNITUDE OF TIME PRESSURE TO ATTAIN SMALL, MEDIUM, AND LARGE LEVELS OF EFFECT

Accuracy		Speed	
r	Magnitude (MAG)	r	Magnitude (MAG)
-.1	.481	.1	.492
-.2	.533	.2	.526
-.3	.587	.3	.561
-.4	.644	.4	.599
-.5	.707	.5	.640

We will focus on the effect of time pressure on performance accuracy, because the emphasis of the stress researcher is likely to be on performance degradation rather than performance enhancement. Table 28 indicates that a time pressure magnitude of .481 is required to produce any discernable effect ($r = .1$) on performance accuracy. Since magnitude of time pressure is computed according to the formula: MAG = longer time period/(longer period + shorter period), a magnitude of .481 corresponds to a 60-second task performed in 59 seconds. To achieve a medium effect ($r = .3$) requires a magnitude of time pressure of .587; or a 60-second task performed in 42 seconds. To achieve a strong effect ($r = .5$) requires a magnitude of time pressure of .707; or a 60-second task performed in 25 seconds.

This relationship suggests two factors to consider in manipulating magnitude of time pressure: (a) almost any manipulation of time pressure "works" (i.e., it will induce some degradation to which the task performer must adapt), and (b) roughly speaking, reducing a baseline task performance period by 1/4 to 1/2 will result in a moderate-to-strong time pressure effect. Furthermore, the regression equation used to compute the

results in Table 28 can be used to predict exact specifications for a task of any given duration.

Studies Included in the Meta-Analysis

Study	Hyp.	Statistic	MG	TP	UR	DL	TK
Bingham & Hailey, 1989	SP	t(35) = .96 (-) [39]	0.89	0	1	1	5
	AC	t(36) = 2.82 (-) [40]	0.89	0	1	1	5
Danev et al., 1972	AC	p = .01 (-) [9]	0.81	0	1	1	5
Farmer et al., 1984	SP	F(1, 52) = 2.55 (+) [15]	0.67	1	0	1	5
	SP	F(1, 52) = 8.73 (+) [15]	0.7	1	0	1	5
	SP	F(1, 52) = 8.27 (+) [15]	0.73	1	0	1	5
	SP	F(1, 52) = 1.84 (+) [15]	0.53	1	0	1	5
	SP	F(1, 52) = 1.63 (+) [15]	0.57	1	0	1	5
	SP	F(1, 52) = .006 (-) [15]	0.54	1	0	1	5
	AC	F(1, 52) = .13 (-) [15]	0.67	1	0	1	5
	AC	F(1, 52) = .11 (+) [15]	0.7	1	0	1	5
	AC	F(1, 52) = 3.41 (-) [15]	0.73	1	0	1	5
	AC	F(1, 52) = .48 (+) [15]	0.53	1	0	1	5
	AC	F(1, 52) = 2.20 (-) [15]	0.57	1	0	1	5
	AC	F(1, 52) = 4.75 (-) [15]	0.54	1	0	1	5
Fischl et al., 1966	AC	X2(1) = .33 (+) [6]	0.88	0	1	1	5
	AC	X2(1) = 3.00 (-) [6]	0.88	0	1	1	2
Goh & Farley, 1977	SP	t(94) = 10.96 (+) [96]	0.78	0	1	1	5
	SP	t(94) = 7.73 (-) [94]	0.78	0	1	1	5
Goolkasian, 1982	SP	F(1, 28) = 30.76 (+) [16]	0.59	1	1	1	6
	SP	F(1, 28) = 281.60 (+) [16]	0.71	1	1	1	6

Study	Hyp.	Statistic	MG	TP	UR	DL	TK
Goolkasian, 1982	SP	F(1, 28) = 126.23 (+) [16]	0.64	1	1	1	6
	AC	F(1, 28) = 28.34 (-) [16]	0.59	1	1	1	6
	AC	F(1, 28) = 133.85 (-) [16]	0.71	1	1	1	6
	AC	F(1, 28) = 39.01 (-) [16]	0.64	1	1	1	6
Huchingson, 1973	AC	F(1, 177) = 108.69 (-) [20]	0.63	1	0	1	3
	AC	F(1, 177) = 118.4 (-) [20]	0.71	1	0	1	3
	AC	F(1, 177) = .22 (-) [20]	0.6	1	0	1	3
Kuhmann et al., 1987	AC	F(1, 63) = 27.93 (-) [68]	0.8	1	1	0	6
Kurz, 1964	SP	p = .05 (+) [40]	0.91	0	1	0	5
	AC	p = .05 (+) [40]	0.91	0	1	0	5
Link, 1971	SP	t(72) = 8.39 (+) [5]	0.64	1	1	1	6
	SP	t(72) = 6.65 (+) [5]	0.68	1	1	1	6
	SP	t(72) = 15.04 (+) [5]	0.79	1	1	1	6
	AC	t(72) = 6.73 (-) [5]	0.64	1	1	1	6
	AC	t(72) = .875 (-) [5]	0.68	1	1	1	6
	AC	t(72) = 7.6 (-) [5]	0.79	1	1	1	6
Link & Tindall, 1971	SP	t(45) = 8.5 (+) [4]	0.64	1	1	1	6
	SP	t(45) = 18.34 (+) [4]	0.7	1	1	1	6
	SP	t(45) = 9.84 (+) [4]	0.57	1	1	1	6
	AC	t(45) = 6.84 (-) [4]	0.64	1	1	1	6
	AC	t(45) = 10.26 (-) [4]	0.7	1	1	1	6
	AC	t(45) = 3.42 (-) [4]	0.57	1	1	1	6
Lulofs et al., 1981	SP	F(1, 11) = 5.54 (+) [4]	0.55	1	0	0	1

Study	Hyp.	Statistic	MG	TP	UR	DL	TK
Lulofs et al., 1981	SP	F(1, 11) = 5.79 (+) [4]	0.6	1	0	0	1
	SP	F(1, 11) = 8.65 (+) [4]	0.67	1	0	0	1
	SP	F(1, 11) = 25.81 (+) [4]	0.75	1	0	0	1
	SP	F(1, 11) = .003 (+) [4]	0.56	1	0	0	1
	SP	F(1, 11) = .35 (+) [4]	0.63	1	0	0	1
	SP	F(1, 11) = 7.44 (+) [4]	0.71	1	0	0	1
	SP	F(1, 11) = .29 (+) [4]	0.57	1	0	0	1
	SP	F(1, 11) = 7.15 (+) [4]	0.67	1	0	0	1
	SP	F(1, 11) = 4.58 (+) [4]	0.6	1	0	0	1
	AC	F(1, 11) = 2.03 (-) [4]	0.55	1	0	0	1
	AC	F(1, 11) = 7.27 (-) [4]	0.6	1	0	0	1
	AC	F(1, 11) = 8.41 (-) [4]	0.67	1	0	0	1
	AC	F(1, 11) = 12.32 (-) [4]	0.75	1	0	0	1
	AC	F(1, 11) = 1.62 (-) [4]	0.56	1	0	0	1
	AC	F(1, 11) = 2.18 (-) [4]	0.63	1	0	0	1
	AC	F(1, 11) = 4.35 (-) [4]	0.71	1	0	0	1
	AC	F(1, 11) = .04 (-) [4]	0.57	1	0	0	1
	AC	F(1, 11) = .66 (-) [4]	0.67	1	0	0	1
	AC	F(1, 11) = .37 (-) [4]	0.6	1	0	0	1
McKinney, 1933	SP	t(78) = 2.24 (+) [80]	0.85	0	1	1	3
	SP	t(78) = 1.82 (+) [80]	0.9	0	1	1	3
	SP	t(78) = .45 (-) [80]	0.63	0	1	1	3
	SP	t(78) = .28 (-) [80]	0.85	0	1	1	5

Study	Hyp.	Statistic	MG	TP	UR	DL	TK
McKinney, 1933	SP	t(78) = 1.18 (+) [80]	0.9	0	1	1	5
	SP	t(78) = 1.24 (-) [80]	0.63	0	1	1	5
	SP	t(78) = 3.7 (+) [80]	0.85	0	1	1	3
	SP	t(78) = 1.06 (-) [80]	0.9	0	1	1	3
	SP	t(78) = 2.21 (+) [80]	0.63	0	1	1	3
	AC	r(78) = .294 (-) [80]	0.85	0	1	1	3
	AC	r(78) = .408 (-) [80]	0.9	0	1	1	3
	AC	r(78) = .105 (-) [80]	0.63	0	1	1	3
	AC	t(78) = .73 (+) [80]	0.85	0	1	1	4
	AC	t(78) = 1.09 (-) [80]	0.9	0	1	1	4
	AC	t(78) = 1.77 (-) [80]	0.63	0	1	1	4
	AC	t(78) = 3.97 (+) [80]	0.85	0	1	1	5
	AC	t(78) = 10.22 (+) [80]	0.9	0	1	1	5
	AC	t(78) = 5.85 (+) [80]	0.63	0	1	1	5
	AC	t(78) = 1.02 (+) [80]	0.85	0	1	1	3
	AC	t(78) = 2.82 (+) [80]	0.9	0	1	1	3
	AC	t(78) = 2.32 (+) [80]	0.63	0	1	1	3
Morris & Liebert, 1969	AC	F(1, 32) = 4.04 (+) [48]	0.89	0	1	1	5
Ward & Poturalski, 1983	SP	t(44) = 2.36 (+) [4]	0.6	1	0	1	3
	SP	t(44) = 8.17 (+) [4]	0.75	1	0	1	3
	SP	t(44) = 5.81 (+) [4]	0.67	1	0	1	3
Yellot, 1971, Experiment 1	SP	F(1, 40) = 0.00 (+) [3]	0.57	1	0	0	1
	SP	F(1, 40) = 0.03 (+) [3]	0.63	1	0	0	1

Study	Hyp.	Statistic	MG	TP	UR	DL	TK
Yellot, 1971, Experiment 1	SP	F(1, 40) = 1.7 (+) [3]	0.56	1	0	0	1
	SP	F(1, 40) = 1.28 (+) [3]	0.67	1	0	0	1
	SP	F(1, 40) = 0.03 (+) [3]	0.62	1	0	0	1
	SP	t(10) = 4.67 (+) [3]	0.8	0	1	0	1
	AC	F(1, 40) = 0.12 (-) [3]	0.57	1	0	0	1
	AC	F(1, 40) = 0.46 (-) [3]	0.63	1	0	0	1
	AC	F(1, 40) = 4.15 (-) [3]	0.67	1	0	0	1
	AC	F(1, 40) = 19.5 (-) [3]	0.7	1	0	0	1
	AC	F(1, 40) = 13.96 (-) [3]	0.73	1	0	0	1
	AC	F(1, 40) = 22.62 (-) [3]	0.77	1	0	0	1
	AC	F(1, 40) = 22.62 (-) [3]	0.84	1	0	0	1
	AC	F(1, 40) = 1.04 (-) [3]	0.56	1	0	0	1
	AC	F(1, 40) = 5.65 (-) [3]	0.6	1	0	0	1
	AC	F(1, 40) = 22.62 (-) [3]	0.64	1	0	0	1
	AC	F(1, 40) = 16.62 (-) [3]	0.67	1	0	0	1
	AC	F(1, 40) = 25.96 (-) [3]	0.71	1	0	0	1
	AC	F(1, 40) = 25.96 (-) [3]	0.8	1	0	0	1
	AC	F(1, 40) = 1.85 (-) [3]	0.55	1	0	0	1
	AC	F(1, 40) = 13.96 (-) [3]	0.58	1	0	0	1
	AC	F(1, 40) = 9.35 (-) [3]	0.62	1	0	0	1
	AC	F(1, 40) = 16.62 (-) [3]	0.67	1	0	0	1
	AC	F(1, 40) = 16.62 (-) [3]	0.76	1	0	0	1
	AC	F(1, 40) = 5.65 (-) [3]	0.54	1	0	0	1

Study	Hyp.	Statistic	MG	TP	UR	DL	TK
Yellot, 1971, Experiment 1	SP	F(1, 40) = 3.67 (+) [3]	0.67	1	0	0	1
	SP	F(1, 40) = 18.94 (+) [3]	0.7	1	0	0	1
	SP	F(1, 40) = 7.28 (+) [3]	0.73	1	0	0	1
	SP	F(1, 40) = 16.03 (+) [3]	0.77	1	0	0	1
	SP	F(1, 40) = 14.67 (+) [3]	0.84	1	0	0	1
	SP	F(1, 40) = 0.03 (+) [3]	0.56	1	0	0	1
	SP	F(1, 40) = 3.67 (+) [3]	0.6	1	0	0	1
	SP	F(1, 40) = 18.94 (+) [3]	0.64	1	0	0	1
	SP	F(1, 40) = 7.28 (+) [3]	0.67	1	0	0	1
	SP	F(1, 40) = 16.02 (+) [3]	0.71	1	0	0	1
	SP	F(1, 40) = 14.67 (+) [3]	0.8	1	0	0	1
	SP	F(1, 40) = 3.03 (+) [3]	0.55	1	0	0	1
	SP	F(1, 40) = 17.46 (+) [3]	0.58	1	0	0	1
	SP	F(1, 40) = 6.37 (+) [3]	0.62	1	0	0	1
	SP	F(1, 40) = 14.67 (+) [3]	0.67	1	0	0	1
	SP	F(1, 40) = 13.37 (+) [3]	0.76	1	0	0	1
	SP	F(1, 40) = 5.94 (+) [3]	0.54	1	0	0	1
	SP	F(1, 40) = .61 (+) [3]	0.57	1	0	0	1
	SP	F(1, 40) = 4.36 (+) [3]	0.63	1	0	0	1
	SP	F(1, 40) = 3.67 (+) [3]	0.73	1	0	0	1
	SP	F(1, 40) = 2.74 (+) [3]	0.53	1	0	0	1
	SP	F(1, 40) = .12 (+) [3]	0.59	1	0	0	1
	SP	F(1, 40) = .27 (+) [3]	0.7	1	0	0	1

Study	Hyp.	Statistic	MG	TP	UR	DL	TK
Yellot, 1971, Experiment 1	AC	F(1, 40) = 2.88 (-) [3]	0.57	1	0	0	1
	AC	F(1, 40) = 7.38 (-) [3]	0.63	1	0	0	1
	AC	F(1, 40) = 7.38 (-) [3]	0.73	1	0	0	1
	AC	F(1, 40) = .46 (-) [3]	0.53	1	0	0	1
	AC	F(1, 40) = .12 (-) [3]	0.59	1	0	0	1
	AC	F(1, 40) = .12 (-) [3]	0.7	1	0	0	1
	AC	F(1, 40) = 1.04 (-) [3]	0.56	1	0	0	1
	AC	F(1, 40) = 1.04 (-) [3]	0.67	1	0	0	1
	AC	F(1, 40) = 0.00 (+) [3]	0.62	1	0	0	1
	AC	t(10) = 19.07 (+) [3]	0.8	0	1	0	1
Yellot, 1971, Experiment 2	SP	F(1, 91) = 134.85 (+) [4]	0.57	1	0	0	1
	SP	F(1, 91) = 221.47 (+) [4]	0.67	1	0	0	1
	SP	F(1, 91) = 478.37 (+) [4]	0.77	1	0	0	1
	SP	F(1, 91) = 587.54 (+) [4]	0.84	1	0	0	1
	SP	F(1, 91) = 10.69 (+) [4]	0.6	1	0	0	1
	SP	F(1, 91) = 105.26 (+) [4]	0.71	1	0	0	1
	SP	F(1, 91) = 159.44 (+) [4]	0.8	1	0	0	1
	SP	F(1, 91) = 48.86 (+) [4]	0.63	1	0	0	1
	SP	F(1, 91) = 87.56 (+) [4]	0.73	1	0	0	1
	SP	F(1, 91) = 5.61 (+) [4]	0.62	1	0	0	1
	SP	t(44) = 2.36 (+) [4]	0.6	1	0	1	3
	SP	t(44) = 8.17 (+) [4]	0.75	1	0	1	3
	SP	t(44) = 5.81 (+) [4]	0.67	1	0	1	3

Study	Hyp.	Statistic	MG	TP	UR	DL	TK
Yellot, 1971, Experiment 2	AC	$F(1, 91) = 9.37$ (-) [4]	0.57	1	0	0	1
	AC	$F(1, 91) = 20.17$ (-) [4]	0.67	1	0	0	1
	AC	$F(1, 91) = 66.67$ (-) [4]	0.77	1	0	0	1
	AC	$F(1, 91) = 70.04$ (-) [4]	0.84	1	0	0	1
	AC	$F(1, 91) = 2.04$ (-) [4]	0.6	1	0	0	1
	AC	$F(1, 91) = 26.04$ (-) [4]	0.71	1	0	0	1
	AC	$F(1, 91) = 28.17$ (-) [4]	0.8	1	0	0	1
	AC	$F(1, 91) = 13.5$ (-) [4]	0.63	1	0	0	1
	AC	$F(1, 91) = 15.04$ (-) [4]	0.73	1	0	0	1
	AC	$F(1, 91) = .04$ (-) [4]	0.62	1	0	0	1

Note:

Hyp. Hypothesis. SP = performance speed, AC = performance accuracy

Statistics: (+) indicates that time pressure improved accuracy or speed

(-) indicates that time pressure led to a decrement in accuracy or speed

Numbers in brackets indicate sample size.

MG: Magnitude. For continuous: low time pressure/high + low time pressure; for categorical: high time pressure/high + low time pressure

TP: Type of time pressure manipulation.
0 = categorical manipulation,
1 = continuous manipulation

UR:	Urging. 0 = No, 1 = Yes
DL:	Deadline. 0 = Simply interrupted when time expired, 1 = Told how much time there is/how much time remaining/reminded of time while performing the task
TK:	Type of task. 1 = reaction; 2 = vigilance; 3 = psychomotor; 4 = short-term memory; 5 = cognitive; 6 = pattern recognition

V. GROUP PRESSURE

Introduction

Individuals may train alone, but they must interact with and work among others on the battlefield. In other words, the environment of a maintenance technician working in a classroom cubicle is quite different from the environment of a busy flightline. One factor that is likely to affect a maintenance technician in the combat environment is the group pressure induced by working in the presence of others on the battlefield.

The effect of others on the individual performer has been termed a double-edged sword (Mullen & Baumeister, 1987). On one hand, working in a group can have performance-enhancing effects. For example, the cohesion provided by group membership can support military personnel in carrying out the combat mission. In fact, in the American Soldier research conducted in World War II, Stouffer et al. (1949) found that combat soldiers identified loyalty to the group as one of the most important factors that "kept them going." The group can often provide the emotional support, cohesion, and motivation necessary for effective individual performance in the harsh military environment.

On the other hand, others have identified the effects of what has been termed "social impairment," the decrement in performance that stems from working in the presence of others. For example, researchers have found that individuals tend to reduce their effort when working in groups; this loss of productivity in groups has been termed "social loafing" (Williams, Harkins, & Latane, 1981). Others have found that highly skilled performers tend to "choke" or perform less well in the presence of others (Baumeister, 1984).

Nature and Theory of Group Pressure Effects

A number of theoretical explanations have been offered to explain the tendency for individuals to perform more poorly when in groups. There are several likely mechanisms at work. Social psychological explanations stress the operation of basic underlying processes engaged by the presence of the other people, and by the individual's membership in the group. For example, the drive-arousal theory (Zajonc, 1965; Geen & Bushman, 1987) argues that the presence of others increases the performer's arousal level. This increase in arousal or drive-level increases the likelihood that the individual will emit a dominant response. Therefore, for simple tasks (that require a dominant or more familiar response for successful performance), the presence of others should facilitate task performance. For complex tasks (which require a less dominant response), the presence of others will impair performance.

Self-attention theory (Carver & Scheier, 1981; Mullen & Baumeister, 1987) provides an alternative explanation for the detrimental effects of the presence of others on individual performance. According to this perspective, when individuals become immersed in a group, they become less self-attentive, and thus less likely to regulate their behavior in accordance with acceptable standards of performance. In other words, individuals in a group become less self-attentive and less likely to notice the difference between what they are currently doing and what they should be doing. This behavior leads to impaired performance.

A third perspective is provided by Cottrell (1972) and others. They claim that it is not simply the presence of others that is potentially detrimental to performance, but the presence of others who can potentially evaluate the individual's performance. According to this perspective, individuals perform more poorly in the presence of others because of evaluator apprehension--the fear of failing while others are present. Finally, it may be that the presence of others is simply more distracting. The distraction/conflict theory (Baron, 1986; Sanders, 1981) holds that on complex tasks, individual performance is impaired because the distraction of others interferes with attention to the task.

Procedural explanations account for the detrimental effects of others on individual performance by emphasizing a breakdown in the procedure or performance of the task itself. In general terms, it is harder to coordinate task performance in the presence of others. For example, Lamm and Trommsdorf (1973) have examined what they called production blocking, whereby individual output in a group can be restrained or blocked because of the increased amount of interaction that occurs when others are present.

Economic explanations argue that the presence of others can impair individual performance because of an intentional withdrawal of effort by the individual. For example, Kerr & Brunn (1983) have observed the tendency of task performers to "free-ride" (lower their performance effort) when in the presence of others. The social-loafing phenomena is another example of reduced effort leading to performance decrements in groups (Latane, Williams, & Harkins, 1979).

This analysis will examine the effects of individual versus group performance on problem-solving tasks that are defined as idea-generation/creative tasks. The analysis is limited to these types of tasks for two reasons. First, researchers agree that creative problem-solving requires two tasks: (a) the generation of a range of possible solutions, and (b) critical evaluation of these solutions to produce the required response (Stein, 1968). The relationship of this process to that which occurs in troubleshooting or fault diagnosis ensures that this literature is relevant to the maintenance technician. Second, there is a consensus on the part of researchers in this area that for this

type of task, groups produce a significant decrement in performance. Since one goal of this project is to identify effective manipulations for stress research, we chose to focus on an area in which we expect to find a strong effect.

Tests of the effectiveness of group versus individual performance on idea generation tasks generally involve a comparison of the performance of individuals interacting in groups with the productivity of individuals in "nominal groups." (Nominal groups are actually individuals performing alone whose outputs are pooled to arrive at a performance rating.) Generally, real groups perform more poorly than individuals (nominal groups.) However, this research does not provide a clear gauge or summary of the extent of performance decrement incurred in groups. Nor do the individual studies allow us to assess the effects of moderators that increase or decrease performance decrement in groups.

Moderators

This meta-analysis examines the effects of group versus individual performance on problem-solving/idea generation tasks. There are two variables that may moderate this relationship: (a) group size, and (b) the presence of the experimenter.

Group Size. Each of the three explanatory mechanisms would predict that productivity loss in groups should increase as a function of group size. As group size increases, there are more people to interrupt the individual and take up more time talking, representing a productivity loss due to procedural mechanisms. As group size increases, there are more people whose presence should arouse or distract the individual, representing a productivity loss due to social psychological mechanisms. Finally, as group size increases, there is more potential to "free-ride", or more co-actors among whom the individual can socially loaf, representing a productivity loss due to economic mechanisms.

Presence of the Experimenter. In some research studies, individuals perform not only in the presence of others, but also in the presence of the experimenter. According to the various social psychological explanations, the presence of the experimenter is likely to increase the magnitude of performance decrement because the experimenter is one more person to arouse, distract, or evaluate the individual performer.

This chapter reports the results of a meta-analytic integration of research examining productivity loss in groups performing problem-solving/idea generation tasks. This meta-analytic integration has three general goals: (1) to provide a precise summary of the significance and magnitude of performance decrement for individuals versus groups, in terms of both the quantity and quality of productivity; (2) to gauge the effect of group size on performance; and (3) to gauge the effect of the presence of the experimenter on performance losses in groups.

Procedure

In accord with the procedures specified in Chapter II of this report, an exhaustive search was conducted to identify studies on group size and performance utilizing several specific search techniques. Using computer-based abstracting services, we searched the Defense Technical Information Center (DTIC) and PSYCHINFO databases. Using the ancestry approach, we searched the bibliographies and reference sections of available reports and articles to identify previous relevant studies. Using the descendency approach, we used indexing sources such as the Social Science Citation Index to locate relevant studies cited in earlier references. In addition, we manually searched major technical journals to identify relevant articles.

Studies were selected for inclusion in this meta-analysis if they reported (or intelligibly implied) a statistical test of the comparison between the performance of groups and the performance of individuals (nominal groups) on idea generation tasks. Studies were eliminated from consideration if the requisite statistical information was not retrievable (e.g., Bouchard, Drauden, & Barsaloux, 1974), if the study failed to report a comparison between a group condition and a nominal condition (e.g., Diehl & Stroebe, 1987, Exp. 2), or if a within-subjects design was employed (e.g., Dunnette, Campbell, & Jaestrad, 1963).

We analyzed the effects of group pressure separately for two outcome measures. The first measure analyzed was quantity of answers on the idea generation tasks. Quantity was gauged as the number of non-redundant ideas or solutions generated. The studies in the analysis yielded a total of 34 hypothesis tests for quantity, representing the responses of 2,577 individuals in 844 groups. The second outcome measure analyzed was quality of answers. Quality was gauged as a rating of the perceived quality of the ideas. The studies in the analysis yielded 9 hypothesis tests for quality, representing the responses of 638 individuals in 244 groups. The hypothesis tests included in this meta-analysis are presented at the end of this chapter.

In the analyses reported below, tests for productivity loss involving quantity and those involving quality were separately subjected to the following meta-analytic procedures: combinations of significance levels and effect sizes, diffuse comparisons of significance levels and effect sizes, and focused comparisons of effect sizes.

Results

General Effects. Table 29 presents the results of the general combinations of significance levels and effect sizes for the 34 hypothesis tests measuring quantitative productivity loss. Table 30 presents results for the nine hypothesis tests measuring qualitative productivity loss. For quantity of performance (i.e., number of ideas generated), the tendency for individuals to perform more poorly in groups has strong magnitude ($r = .572$)

and is statistically significant ($p < .001$). For quality of performance (quality of ideas generated), the tendency for individuals to perform more poorly in groups also has strong magnitude ($r = .558$) and is significant ($p < .001$).

TABLE 29. GENERAL COMBINATIONS OF SIGNIFICANCE LEVELS AND EFFECT SIZES: GROUP PRESSURE AND QUANTITY OF PERFORMANCE

34 Hypothesis Tests (weighted by sample size)

Combination of Significance Levels
Z for combination = 15.324
Associated one-tailed $p < .001$
Fail-safe number ($p = .05$) = 2,827

Combination of Effect Sizes
Mean Fisher's Z = .650
Mean r = .572
Mean r^2 = .327

TABLE 30. GENERAL COMBINATIONS OF SIGNIFICANCE LEVELS AND EFFECT SIZES: GROUP PRESSURE AND QUALITY OF PERFORMANCE

9 Hypothesis Tests (weighted by sample size)

Combination of Significance Levels
Z for combination = 10.59
Associated one-tailed $p < .001$
Fail-safe number ($p = .05$) = 252

Combination of Effect Sizes
Mean Fisher's Z = .630
Mean r = .558
Mean r^2 = .311

Group Size. Table 31 presents the correlation between Z for effect size and group size, as well as the corresponding focused comparison of effect sizes for quantity and quality of performance. For quantity, the correlation between Z for effect size and the size of the group for each study was $r = .606$. The meta-analytic focused comparison of effect sizes was $Z = 19.13$, $p < .001$. For quality, the same pattern was demonstrated: $r = .715$, $Z = 9.528$, $p < .001$. Thus, consistent with each of

the explanatory mechanisms considered above, productivity loss increases as the size of the group increases.

TABLE 31. EFFECTS OF GROUP SIZE

	Quantity	Quality
r	.606	.715
Focused Comparison		
Z	19.130	9.528
p	<.001	<.001

Experimenter Presence. Table 32 presents the results of separate combinations of significance levels and effect sizes, and the corresponding focused comparisons, for hypothesis tests where the experimenter was present during task performance, and for hypothesis tests where the experimenter was absent. The results reveal a significantly greater productivity loss for quantity when the experimenter was present than when the experimenter was absent (Z for comparison = 3.375, $p < .001$). There was no effect of experimenter presence for quality of performance (Z for comparison = .410, $p = .341$).

Summary

The overall effects of group pressure on quantity and quality of performance are presented in Table 33. The meta-analytic results reveal that, for both quantitative and qualitative operationalizations, productivity loss in groups performing idea generation tasks is highly significant and of strong magnitude. Thus, these data provide clear and consistent evidence that performing in a group or team leads to significant degradation on problem solving tasks requiring idea generation. Furthermore, this degradation is more pronounced as groups increase in size, and the performance decrement is shown to be stronger in laboratory research when an experimenter is present during task performance.

It is likely that the performance decrement experienced by individuals performing these tasks in groups is attributable to several phenomena. Distraction, arousal, attention deficits, and the pressure of being evaluated by others are likely contributing factors. Whereas researchers hold differing opinions on the underlying theory explaining this performance degradation, there is no question that the phenomenon exists. And, based on the current research, we now have a gauge of the significance and magnitude of effect of this phenomenon, and guidelines for

TABLE 32. RESULTS OF COMBINATIONS AND FOCUSED COMPARISONS INVOLVING EXPERIMENTER PRESENCE

	Quantity	Quality
Experimenter Present		
k	8	4
Significance Levels		
Z	9.998	11.507
p	<.001	<.001
Effect Sizes		
Z	0.747	0.956
r	.633	.742
r^2	.401	.551
Experimenter Absent		
k	16	1
Significance Levels		
Z	9.004	2.498
p	<.001	.006
Effect Sizes		
Z	0.623	0.976
r	.553	.751
r^2	.306	.565
Focused Comparisons		
Z	3.375	0.410
p	<.001	.341

manipulating group size in the research laboratory. In summary, group pressure is a very effective (and easily manipulated) stressor.

Guidelines for Manipulating Group Pressure

Table 34 provides specific information on manipulating group size to achieve a significant effect on performance. Using Cohen's (1977) benchmarks for effect size, our results indicate that working in a group of two presents enough of a distraction to produce a small or weak-to-moderate effect on performance ($r = .17$); working in a group of three produces a medium-to-large effect ($r = .42$); and working in a group of four produces a very strong effect ($r = .63$). Therefore, to achieve a medium-to-large performance effect using group pressure as a stress manipulation requires that at least two others be present. Furthermore, the presence of the experimenter increases the stress effect.

TABLE 33. GROUP PRESSURE: SUMMARY OF OVERALL EFFECTS

	Quantity	Quality
Significance Levels		
$z_{significance}$	15.324	10.590
p	< .001	< .001
Effect Sizes		
z_{Fisher}	.650	.630
r	.572	.558
r^2	.327	.311

TABLE 34. MANIPULATION OF GROUP SIZE TO OBTAIN SMALL, MEDIUM, AND LARGE LEVELS OF EFFECT

r	Group Size
.17	2
.42	3
.63	4

A significant amount of maintenance training takes place in the shop or classroom with one technician working on one piece of equipment. Yet the combat environment is likely to be one in which other personnel predominate. Because of the dramatic effects of group pressure on performance (summarized in this analysis), group pressure should be considered as a component of an effective stress simulation. It would be well-advised to develop simulations that provide the capability to manipulate group size for those tasks which will in fact be performed as part of a group, team, or crew, or simply performed in the presence of others on the combat battlefield.

Studies Included in the Meta-Analysis

Study	Hyp	Statistics	Z	r	GS	EP
Barkowski, et al., 1982	QN	t(76)=2.44 (+) [156]	2.39	.270	2	1
	QN	t(76)=4.12 (+) [156]	3.90	.427	2	1
Bouchard & Hare, 1970	QN	t(12)=3.71 (+) [40]	2.96	.731	5	1
	QN	t(12)=8.47 (+) [56]	4.73	.926	7	1
	QN	t(12)=11.59 (+) [72]	5.36	.958	9	1
Casey, et al., 1984, Experiment 2	QN	t(56)=4.10 (+) [80]	3.82	.480	2	0
	QL	t(56)=5.32 (+) [80]	4.76	.579	2	0
	QN	t(56)=1.92 (-) [80]	-1.88	-.249	2	0
	QL	t(56)=0.99 (-) [80]	-.098	-.131	2	0
Cohen, et al., 1960	QN	F(1,18)=.255 (-) [48]	-0.50	-.118	2	0
	QN	F(1,18)=.005 (-) [48]	-0.07	-.017	2	0
	QN	F(1,18)=.0006 (+) [48]	0.02	.006	2	0
Diehl & Stroebe, 1987, Experiment 1	QN	F(1,8)=87.56 (+) [48]	4.31	.957	4	1
	QL	F(1,8)=10.38 (+) [48]	2.50	.751	4	1
Diehl & Stroebe, 1987, Experiment 3	QN	F(1,8)=74.08 (+) [64]	4.18	.950	4	2
Diehl & Stroebe, 1987, Experiment 4	QN	t(10)=3.64 (+) [12]	2.83	.755	4	2

Study	Hyp.	Statistics	Z	r	GS	EP
Dillon et al., 1972	QN	F(1,16)=110.7 (+) [96]	5.66	.935	4	0
Graham, 1977	QN	p=.01 (+) [128]	2.33	.206	4	0
Gurman, 1968	QN	t(48)=5.77 (+) [54]	5.00	.640	3	2
	QL	t(48)=3.96 (+) [54]	3.66	.496	3	2
Harari & Graham, 1975	QN	F(1,24)=243.7 (+) [128]	7.53	.954	4	0
Jablin et al., 1977	QN	F(1,25)=0.20 (-) [124]	-0.44	-.089	4	2
Jablin, 1981	QN	F(1,20)=7.61 (+) [104]	2.51	.525	4	1
Madsen & Finger, 1978	QN	t(6)=.058 (+) [32]	0.06	.024	4	1
	QN	t(6)=.243 (+) [32]	0.23	.009	4	1
	QN	t(6)=3.15 (+) [32]	2.32	.789	4	1
	QN	t(6)=.943 (-) [32]	-0.87	-.359	4	1
Maginn & Harris, 1980	QN	F(1,26)=16.23 (+) [50]	3.52	.620	4	1
	QN	F(1,26)=.20 (+) [125]	0.44	.087	4	2
Milton, 1965	QN	p=.05 (+) [48]	1.65	.237	4	0
	QL	p=.05 (+) [48]	1.65	.237	4	0
Pape & Bolle, 1984	QN	t(44)=.62 (+) [92]	0.62	.093	2	1
	QN	t(44)=.68 (+) [92]	0.67	.102	2	1

Study	Hyp.	Statistics	Z	r	GS	EP
Rotter & Portugal, 1969	QN	t(16)=3.87 (+) [64]	3.20	.695	4	1
	QN	t(16)=2.19 (+) [96]	2.02	.480	4	1
Taylor et al., 1958	QN	t(44)=8.96 (+) [96]	6.72	.804	4	2
	QL	F(1,44)=43.5 (+) [96]	5.47	.705	4	2
	QN	t(44)=9.38 (+) [96]	6.91	.816	4	2
	QL	F(1,44)=114.6 (+) [96]	7.47	.850	4	2
	QN	t(44)=9.26 (+) [96]	6.86	.813	4	2
	QL	F(1,44)=55.5 (+) [96]	5.96	.747	4	2
Torrence, 1970	QN	t(38)=1.002 (-) [40]	-0.99	-.160	2	0
	QL	t(38)=4.326	-3.88	-.574	2	0

Note:

Hyp.: Hypothesis. QN = Quantity; QL = Quality

Statistics: (+) indicates that individuals performed better than groups

(-) indicates that groups performed better than individuals

Numbers in brackets represent sample size

GS: Group Size

EP: Experimenter Presence. 2 = experimenter present; 1 = experimenter absent; 0 = not known

VI. THREAT

Introduction

Evidence from a broad range of studies suggests that when performing in dangerous environments, subjective anxiety increases and performance suffers. For example, studies of military parachuting report increased subjective anxiety for trainees just before and during early jumps (Grierson, 1975; Halse, Blix, Ellerston, & Ursin, 1978). Investigators have documented a variety of performance impairments in threatening situations. For example, in a study of deep diving, Mears & Cleary (1980) discovered that manual dexterity decreases as the depth of the dive increases. In a review of tracking performance, Bergstrom (1970) found many instances of impairment when subjects were threatened, for example with electrical shock. This chapter examines the effect of fear or threat on performance and subjectively reported stress.

Nature and Theory of Threat Effects

Friedman (1981) made an important distinction between fear and anxiety. He described anxiety as a situation in which one is aroused due to the anticipation of a physically innocuous situation that generates embarrassment or discomfiting self-consciousness. In contrast, he described fear as a situation in which one is aroused due to anticipation of an actual physical stimulus perceived by a person as capable of directly causing pain or discomfort. This notion of fear as opposed to anxiety is more clearly related to the threat experienced in the wartime maintenance environment. For the purposes of this research, we will define threat as follows:

Threat: Anticipation of or fear of physical harm

Investigators have used numerous manipulations with the intent of inducing fear or threat. These manipulations have ranged from threatening to inflict mild electrical shock (Bloom, Houston, & Burish, 1976; Keinan, 1987) to actually inflicting mild electrical shock (Cox, 1984; Monat, Averill, & Lazarus, 1972) to leading subjects to believe that they were in grave danger of actually losing their lives (Berkun, Bialek, Kern, & Yagi, 1962). Although a variety of threat manipulations have been reported in the research literature, by far the most commonly used are threat of shock and actual delivery of shock.

Other investigators have taken advantage of military or sports training exercises which are inherently threatening. For example, sports and military parachuting has been examined by Burke (1980) and others. Subjective reports of stress as well as performance measures have been taken either preceding or during early jumps from high towers, balloons, or aircraft. Deep diving is another area that has received attention. Unfortunately, the

relatively small pool of studies in these areas and the large variety of dependent variable measures make them less than ideal domains for meta-analytic integration.

Ethical problems arise when subjects are put into situations designed to cause intense fear without informing them that this is the purpose of the experiment. For this reason, some investigators have tried to circumvent this problem by studying the effects of naturally occurring situations such as earthquakes and floods. Unfortunately, these situations tend to be inaccessible and unpredictable. Worse yet, they affect the experimenter as much as the victims and rarely allow clear, objective performance measurements.

This analysis will focus on studies assessing the effects of threat of electrical shock on performance accuracy and subjective reports of stress. The domain of shock has been chosen for three reasons. First, the threat induced by shock is relevant to the battlefield situation. That is, it results in the anticipation of or fear of physical harm, just as the battlefield leads to such anticipation or fear. Second, by far, the majority of studies in the area of threat have involved shock or threat of shock. Third, by limiting this preliminary analysis to a single operationalization of threat, we can avoid obscuring critical differences as a result of mixing findings from studies with different operationalizations.

<u>Moderators</u>

The effects of shock on performance may be moderated by a number of factors, including whether or not the shock was actually delivered and by the number of shocks.

<u>Delivery</u>. Some investigators actually shocked subjects, whereas others threatened subjects with shock, but did not actually shock them. For example, Bloom et al. (1976) told subjects in the threat group that they would receive a series of electrical shocks of increasing intensity during the experiment, although none were actually delivered. Cox (1984) informed subjects that they would be receiving mild electrical shocks, but could avoid these shocks by improving their performance from one trial to the next. Here, subjects were actually shocked.

<u>Number of Shocks</u>. Studies in which shock was administered vary on the number of shocks given to subjects. It is reasonable to assume that the number of shocks received by subjects would moderate their appraisal of the stressfulness of the situation, with more shocks leading to more negative appraisals.

<u>Procedure</u>

An exhaustive search was conducted to identify studies of the effect of shock on performance and subjectively reported

stress utilizing several specific search techniques. Using computer-based abstracting services, we searched the DTIC and PSYCHINFO databases. Using the ancestry approach, we searched the bibliographies and reference sections of obtained reports and articles to identify previous relevant studies. Using the descendency approach, we used indexing sources such as the Social Sciences Citation Index to locate relevant studies cited in earlier references. In addition, we manually searched major technical journals to identify relevant articles.

Studies were included in the meta-analysis if they reported the effect of a shock condition versus that of a no shock condition on subjective stress or performance accuracy. Studies were eliminated from consideration if the basic statistical information required for analysis was not retrievable.

The studies in the analysis yielded a total of 30 hypothesis tests for the effects of shock on subjectively reported stress and 24 hypothesis tests for the effects of shock on performance accuracy. The hypothesis tests included in this meta-analysis are presented at the end of this chapter.

Results

General Effects. Table 35 presents results of the analysis of 30 hypothesis tests of the effect of shock on self-report. These results indicate that the effects of shock on self-report are significant ($p < .001$) and of moderate-to-high magnitude ($r = -.345$) in the direction of shock leading to unpleasant feelings of stress.

TABLE 35. GENERAL COMBINATIONS OF SIGNIFICANCE LEVELS AND EFFECT SIZES: THREAT AND SELF-REPORT

30 Hypothesis Tests (weighted by sample size)

Combination of Significance Levels
Z for combination = -16.286
Associated one-tailed p = < .001

Fail-safe number (p = .05) = 2714

Combination of Effect Sizes
Mean Fisher's Z = -.348
Mean r = -.335
Mean r^2 = .112

Table 36 presents results of the analysis of 24 hypothesis tests of the effect of shock on self-report. These results

indicate that people tend to perform less accurately when confronted by the threat of shock. This tendency is rather small ($r = -.160$), yet significant ($p < .001$).

TABLE 36. GENERAL COMBINATIONS OF SIGNIFICANCE LEVELS AND EFFECT SIZES: THREAT AND PERFORMANCE ACCURACY

24 Hypothesis Tests (weighted by sample size)

Combination of Significance Levels
Z for combination = − 5.790
Associated one-tailed $p < .001$

Fail-safe number ($p = .05$) = 274

Combination of Effect Sizes
Mean Fisher's Z = −.162
Mean $r = -.160$
Mean $r^2 = .026$

Delivery. Table 37 presents the results of separate combinations of significance levels and effect sizes and the corresponding focused comparison for hypothesis tests in which the subjects were actually shocked and for those in which the subjects were threatened with shock, but never actually shocked. When shock was delivered, there was a small-to-moderate effect ($r = -.242$) in the direction of increased self-reported stress. However, a stronger negative impact on effect was produced when shock was threatened but never actually produced ($r = -.410$). Interestingly, the threat of shock without actual delivery resulted in significantly higher ratings of unpleasantness than actual delivery of shock (Z for comparison = 3.969, $p < .001$).

As was the case with self-report, whether or not shock was actually delivered had an influence on performance accuracy (Z for comparison = 1.724, $p = .042$). Performance suffered more when the shock was not delivered ($r = -.205$) than when it was delivered ($r = -.116$). For both subjectively reported stress and performance accuracy, apparently, the anticipation of physical harm is a more powerful force than the harm itself.

Number of Shocks. Table 38 presents the results of a focused comparison of effect sizes for number of shocks delivered. As might be expected, for studies in which shock was actually delivered, the higher the number of shocks delivered, the higher were the ratings of unpleasantness. This relationship was statistically significant ($p = .003$).

The number of shocks delivered affected accuracy in an unexpected way. There was a tendency for the delivery of more shocks to be associated with greater accuracy ($r = .273$), although this tendency is not statistically significant.

TABLE 37. EFFECTS OF THREAT WITHIN DELIVERY

	Self-Report	Accuracy
Delivered		
Significance Levels		
$Z_{significance}$	7.750	3.062
p	< .001	.001
Effect Sizes		
Z_{FISHER}	-.247	-.117
r	-.242	-.116
r^2	.059	.014
Not Delivered		
Significance Levels		
$Z_{significance}$	14.450	5.104
p	< .001	< .001
Effect Sizes		
Z_{FISHER}	-.435	-.208
r	-.410	-.205
r^2	.168	.042
Focused Comparison		
Z	3.969	1.724
p	< .001	.042

TABLE 38. EFFECTS OF NUMBER OF SHOCKS

	Self-Report	Accuracy
Delivered		
r	-.617	.273
Focused Comparison		
Z	2.751	2.127
p	.003	.017

Summary

One goal of this meta-analysis is to specify the effects of threat on self-reported stress in order to provide the stress researcher with practical and precise guidelines for manipulating threat. The results of this analysis are summarized below and in Table 39.

TABLE 39. SHOCK: SUMMARY OF OVERALL EFFECTS

	Self-Report	Accuracy
Significance Levels		
$Z_{significance}$	-16.286	-5.790
p	< .001	< .001
Effect Sizes		
Z_{FISHER}	-.348	-.162
r	-.335	-.160
r^2	.112	.026

General Effect of Threat of Shock

Self-Report: Moderate-to-strong relationship between threat of shock and self-reported stress.

Performance Accuracy: Small negative effect of threat of shock impairing performance accuracy.

Effect of Delivery

Self-Report: Self-report is more negative when shock is threatened, but never actually delivered.

Performance Accuracy: Performance accuracy suffers more when shock is threatened, but never actually delivered.

Effect of Number of Shocks

Self-Report: More negative self-report with higher number of shocks.

Performance Accuracy: Slight, yet insignificant effect for less decrement in performance accuracy with higher number of shocks.

Guidelines for Manipulating Threat

These results suggest that threat of shock will function as a strong and effective manipulation to impose both perceived stress and stress-related performance decrements. Table 40 shows how we would differentially manipulate threat of shock to affect self-report (perceived stress) and performance accuracy.

In order to impart the "feeling" of stress, as in a confidence drill, the effect of threat could be maximized by threatening, but never actually delivering shock. If shocks are delivered, then a greater quantity of them will result in greater self-reported stress.

For skills training, the effect of threat could also be maximized by threatening, yet never actually delivering shock. If the experimenter chooses to actually deliver shocks, the number of shocks will not make much difference.

TABLE 40. THREAT MANIPULATIONS FOR CONFIDENCE DRILL VERSUS SKILLS TRAINING

	Self-Report	Performance Accuracy
General Effects	Moderate-to-strong effect of threat on perceived stress	Small, significant effect of threat on performance accuracy
Threat Delivered/ Not Delivered	Stronger effect when threat is not actually delivered	Stronger effect when threat is not actually delivered
Number of Shocks	Stronger effect with increasing number of shocks	Slight, yet insignificant tendency for a stronger effect with increasing number of shocks

Studies Included in the Meta-Analysis

Study	Hyp	Statistic	IN	PE	DV	#
Bloom, Houston, & Burish, 1976	SR	F(1, 190) = 64.89 (-) [192]	0.3	1	0	0
Carron, 1968	AC	F(1, 114) = 4.26 (-) [120]	---	0	1	6
Coulter, 1970	AC	t(18) = .673 (-) [20]	---	0	1	1
	AC	t(18) = 2.76 (-) [20]	---	0	1	1
	AC	t(18) = 1.816 (-) [20]	---	0	1	1
	AC	t(18) = 1.01 (+) [20]	---	0	1	1
Cox, 1983	SR	t(94) = 4.98 (-) [96]	2.5	0	1	4
	AC	t(90) = .605 (-) [64]	2.5	0	1	4
Cox, 1984	SR	t(78) = 3.19 (-) [80]	2.5	0	1	7.25
	SR	t(78) = 3.82 (-) [80]	2.5	0	1	7.25
Friedman, 1981 Experiment 2	AC	t(.101) = 1.15 (-) [40]	0	0	0	0
Harris, 1981	SR	t(108) = 1.15 (-) [80]	1	1	1	3
	SR	t(108) = 2.57 (-) [80]	1	1	1	3
Holmes & Houston, 1974	SR	t(14) = 4.64 (-) [16]	0	0	0	0
Houston, 1972	SR	t(60) = 1.84 (-) [44]	0	0	0	0
	SR	t(60) = 2.74 (-) [44]	0	0	0	0
Houston & Holmes, 1974	SR	F(1, 44) = 4.63 (-) [48]	0	0	0	0
Houston et al., 1978	SR	F(1, 98) = 19.83 (-) [100]	0.1	1	0	0
Keinan, 1987	SR	t(97) = 6.27 (-) [67]	0	0	0	0
	SR	t(97) = 6.27 (-) [67]	0	0	0	0
	AC	F(1, 36) = 11.29 (-) [38]	0	0	0	0
	AC	t(98) = 3.43 (-) [67]	0	0	0	0

Study	Hyp	Statistic	IN	PE	DV	#
Keinan, 1987	AC	t(98) = 4.89 (-) [67]	0	0	0	0
Landers & Martens, 1971	SR	t(116) = 1.26 (-) [81]	1	0	0	0
	SR	t(116) = 3.64 (-) [81]	2.5	0	0	0
	AC	t(116) = .621 (-) [81]	0	0	0	0
	AC	t(116) = .483 (+) [81]	0	0	0	0
Lee, 1961	AC	F(1, 56) = .03 (-) [60]	---	1	1	7
Marteniuk & Wenger 1970	AC	t(27) = .127 (-) [20]	5	1	1	3
	AC	t(27) = .051 (+) [20]	.5	1	1	3
Martens & Landers, 1970	AC	t(72) = 2.25 (+) [60]	0	0	0	0
	AC	t(72) = 4.85 (-) [60]	0	0	0	0
Monat et al., 1972 Experiment 1	SR	t(152) = 4.72 (-) [20]	2.5	0	0	0
	SR	t(152) = 3.51 (-) [20]	2.5	0	1	3
	SR	t(152) = 1.63 (-) [20]	2.5	0	1	3
	SR	t(152) = 1.63 (-) [20]	2.5	0	1	3
Experiment 2	SR	t(216) = .39 (+) [40]	2.5	0	1	3
	SR	t(216) = .34 (-) [40]	2.5	0	1	3
	SR	t(216) = .83 (-) [40]	2.5	0	1	3
	SR	t(216) = 3.07 (-) [40]	2.5	0	1	3
Ryan, 1961	AC	F(1, 38) = .30 (-) [40]	4.4	0	1	8
Ryan, 1962	AC	F(1, 116) = .18 (-) [40]	4.4	0	1	7
Ryan, 1962	AC	t(152) = 2.25 (-) [60]	4.4	0	1	7
Sage & Bennett, 1973	SR	t(39) = 2.30 (-) [28]	1.6	0	1	4
	SR	t(39) = .95 (-) [28]	1.6	0	1	4

Study	Hyp	Statistic	IN	PE	DV	
Sage & Bennett, 1973	AC	t(39) = .388 (-) [28]	1.6	0	1	4
	AC	t(39) = .034 (+) [28]	1.6	0	1	4
Thackray & Pierson, 1968	AC	t(42) = 2.48 (-) [32]	0	0	0	0
	AC	t(42) = 2.18 (-) [32]	0	0	0	0

Hyp.: Hypothesis. SR = self-reported stress; AC = performance accuracy.

Statistics: (+) indicates that shock improved accuracy or led to a more favorable self-report

(-) indicates that shock led to a decrement in accuracy or a more negative self-report

Numbers in brackets indicate sample size.

IN: Intensity of shock

PE: Previous exposure to shock: 1 = yes, 0 = no

DV: Delivery: 1 = shock was delivered, 0 = shock was not delivered

#: Number of shocks delivered

VII. UNCONTROLLABILITY

Introduction

Humans have a strong need to master their environment. When they are exposed to aversive, stressful events over which they have no control, individuals experience not only the aversive situation, but also the anxiety of being incapable of doing anything about it. Lazarus (1966) proposed that the less control one has in a threatening situation, the more helpless one feels, and the more unpleasant the situation will seem. Conversely, if one feels able to counter or avoid physical harm, the situation should be less threatening and unpleasant. A host of negative consequences have been associated with lack of control, including negative effect, cognitive deficits, reduced motivation, and learned helplessness (Seligman, 1975). For these reasons, it is important to understand the role of uncontrollability as a combat-relevant stressor.

Nature and Theory of Uncontrollability

As Thompson (1981) notes, most of the studies that manipulate control do not provide a formal definition of the concept. Thompson defines control as "the belief that one has at one's disposal a response that can influence the aversiveness of an event"(p. 89). Importantly, this definition recognizes that the control does not necessarily have to be exercised for it to be effective and that it does not even have to be real; it only has to be perceived for it to have effects.

Averill (1973) and Thompson (1981) distinguish between behavioral and cognitive control. Behavioral control is defined as a belief that one has a behavioral response available that can lessen the aversiveness of, or preclude, a threatening event. Behavioral control can take several forms. Sometimes, the individual is given some control over variables such as who administers the stimulus (oneself or another) and how and when the stimulus will be encountered. Other times, the individual is given the means to actually avoid the noxious event altogether (e.g., improving performance, pushing a button to avoid the stimulus, or being told that one can leave at any time).

Cognitive control is the belief that one has a cognitive response available that can lessen the aversiveness of, or preclude, a threatening event. Cognitive control concerns the way a threatening event is interpreted. Two types of cognitive control may be distinguished: information gain and appraisal.

By obtaining information regarding upcoming noxious events, much of the stress-producing uncertainty can be eliminated. Information gain refers to letting an individual know something in advance about an aversive event to be experienced. One example of information gain is informing a surgical patient of

the sensations likely to be experienced during surgery. In a laboratory setting, the simplest form of information gain is a warning signal given before the administration of a noxious stimulus such as a shock or loud noise.

Staub & Kellet (1972) examined the value of two types of knowledge concerning impending electrical shock. Subjects were given information about (1) the objective characteristics of the shock (e.g., the nature of the delivery apparatus and its safety features) and (2) the nature of the sensations they would experience. Subjects who received the information expressed less anxiety than those who did not receive it.

Predictability may be a form of information, thus engendering cognitive control. D'Amato & Gumenik (1970) found that individuals prefer predictable shock to unpredictable shock. Pervin (1963) found predictable shock to be less arousing than unpredictable shock. On the other hand, Monat, Averill, and Lazarus (1972) found that knowing when to expect an electrical shock (indicated by a clock) led to greater anticipatory stress reactions.

Appraisal refers to an individual actively imposing meaning on events. Here, the individual typically gains some feeling of control by modifying the perception of the threat to conform to personal desires. As with other forms of individual control, appraisals have the potential to either increase or decrease stress reactions. Worry is considered one form of appraisal. According to Janis (1958), worry is a form of inner preparation that increases the level of tolerance for subsequent noxious stimuli, but produces more immediate stress. Janis found that surgical patients who experienced too little or too much fear prior to an operation evidenced less rapid recovery than did patients who displayed moderate stress reactions prior to surgery. Presumably, worry as a cognitive strategy prepared the latter patients for the surgical trauma that followed.

Studies of the effects of chronic exposure to uncontrollable environmental stressors (such as overcrowded and noisy living conditions) have shown that these stressors can result in psychological problems. One common psychological reaction to chronic exposure to uncontrollable stressors is learned helplessness (Evans and Cohen, 1987). If individuals cannot assert control over an environmental source of stress, they may learn that their behavior has little effect on outcomes. Helplessness may result when coping efforts fail to modify an environmental source of stress.

For example, it has been found that people who reside in noisy settings are more susceptible to learned helplessness (Cohen, Evans, Krantz, & Stokols, 1980; Cohen et al., 1981; Cohen et al., 1986). In a similar vein, people who have had to endure crowded conditions have also been found to be more

susceptible to learned helplessness (Rodin, 1976; Baum & Paulus, 1987).

Thus, there is considerable evidence that chronic exposure to environmental stressors can cause negative reactions because of restrictions in individual control. Importantly, by providing actual or perceived control over stressors, such negative effects may be partially ameliorated. Studies on crowding (Baum & Paulus, 1987; Epstein, 1982), noise (Cohen & Weinstein, 1981), air pollution (Evans and Jacobs, 1982), and heat (Bell & Greene, 1982) have found complete or partial amelioration of many negative impacts of exposure to these environmental stressors when individuals were equipped with instrumental control over the stressor. Interestingly, when subjects believe they can personally control the environment--whether through access to a noise termination switch or by virtue of prior successful escape responses--their performance is less affected by the stressors, even when control is not actually exercised.

Many of the laboratory studies of the effects of uncontrollability have used threat of shock as a stressor. A number of studies (Champion, 1950; Corah & Boffa, 1970; Bowers, 1968; Houston, 1972; Szpiler & Epstein, 1976) have found that subjects reported less stress when they believed they had behavioral control in a situation (i.e., they could terminate or avoid the electrical shock). A number of researchers have found that control reduces arousal as the subject anticipates receiving shock (Geer et al., 1970; Szpiler & Epstein, 1976).

Most studies of the effects of controllable versus uncontrollable shock have defined control in terms of a performance contingency. For example, in Houston's (1972) study, in a no-control condition subjects were led to believe that there was no way of avoiding an electric shock which would occur randomly while they performed a memory task. This condition was designed to encourage the subjects to feel helpless, since they could not counter or avoid the shock. In a second condition, subjects were told they could avoid the electrical shock by avoiding errors during the memory task. In contrast to the first condition, this one was designed to encourage subjects to feel that they possessed some control over the situation (i.e., they could counter or avoid the threat through their performance). Obviously, in these situations, subjects receive less than complete control over what happens to them: they are not led to believe that it will be easy or definite that they can avoid the shock. Basically, they are challenged to avoid the shock.

Moderators

Delivery. Whether shock is actually delivered or not may interact with controllability. Some investigators actually shocked subjects, whereas others threatened subjects with shock, but did not actually shock them. For example, Bloom et al.(1976)

told subjects in the threat group that they would receive a series of electrical shocks of increasing intensity during the experiment, although none were actually delivered. Cox (1984) informed subjects that they would be receiving mild electrical shocks, but could avoid these by improving their performance from one trial to the next.

Some research has failed to unearth either physiological or self-reported stress differences in groups with control versus groups without control (Averill & Rosenn, 1972; Averill, O'Brien, & deWitt, 1977). It is interesting to note that in instances where shock was actually delivered, there is some indication that behavioral control does not lead people to report that they experienced less distress in reaction to the shock (Averill & Rosenn, 1972; Pervin, 1963; Staub et al., 1971).

Procedure

Only studies assessing the effects of uncontrollable shock were used because this was by far the most common manipulation of uncontrollability in the literature. An exhaustive search was conducted to identify studies on the effects of shock and uncontrollability on performance and subjectively reported stress utilizing several specific search techniques. Using computer-based abstracting services, we searched the Defense Technical Information Center (DTIC) and PSYCHINFO databases. Using the ancestry approach, we searched the bibliographies and reference sections of obtained reports and articles to identify previous relevant studies. Using the descendency approach, we used indexing sources such as the Social Sciences Citation Index to locate relevant studies cited in earlier references. In addition, we manually searched major technical journals to identify relevant articles.

This analysis is limited to studies which assessed the effect of threat of shock on self-reported stress or performance accuracy. Coding for each hypothesis test from these studies depended on whether control over receiving or not receiving electrical shock was delegated to the subject by the experimenter. Studies were eliminated from consideration if the basic statistical information required for analysis was not retrievable.

The studies in the analysis yielded a total of 30 hypothesis tests for the effects of shock on subjectively reported stress and 24 hypothesis tests for the effects of shock on performance accuracy. The hypothesis tests included in this meta-analysis are presented at the end of this chapter.

Results

General Effects of Controllability. Table 41 presents the results of separate combinations of significance levels and effect sizes. It also shows the corresponding focused comparison of hypothesis tests in which the subjects had some control and those in which the subjects had no control. Receiving some control (where shock was contingent on poor performance) did not significantly ameliorate the negative feelings subjects reported in threatening situations, nor did it improve performance accuracy. There was a moderate and significant tendency for shock to lead to a negative self-report of stress whether subjects had control ($r = -.354$, $p < .001$) or did not have control ($r = -.322$, $p < .001$). Likewise, performance accuracy was impaired to a small extent whether subjects had control ($r = -.158$, $p < .001$) or did not have control ($r = -.166$, $p < .001$). A focused comparison of effect sizes for the control variable showed that it did not have a significant influence on

TABLE 41. EFFECTS OF SHOCK WITHIN LEVELS OF CONTROL

	Self-Report	Accuracy
Controllable		
Significance Levels		
$Z_{significance}$	9.236	-3.642
p	<.001	<.001
Effect Sizes		
Z_{FISHER}	-.370	-.159
r	-.354	-.158
r^2	.125	.025
Uncontrollable		
Significance Levels		
$Z_{significance}$	11.513	-4.542
p	< .001	< .001
Effect Sizes		
Z_{FISHER}	-.334	-.166
r	-.322	-.164
r^2	.104	.027
Focused Comparison		
Z	1.171	.642
p	.121	.260

self-report ($p = .121$) or performance accuracy ($p = .260$). This counterintuitive result becomes more interpretable when we examine the effect of uncontrollability according to whether or not the shock was actually delivered.

Control and Delivery. Table 42 displays separate combinations of significance levels and effect sizes for each of the four possible combinations of controllability and delivery. The largest impairment of accuracy occurred when subjects had no control and never actually received shock ($r = -.300$). The next largest decrement resulted from the subjects having control and not receiving shocks ($r = -.172$). The final two situations: (a) no control, shocks delivered and (b) control, shocks delivered were essentially identical in the resulting performance decrement ($r = .116$) for both. Thus, for accuracy, the largest impairments occurred when shock was never delivered, especially when subjects did not have control. When shock was delivered, control made no difference.

The relationship between delivery and controllability for self-report is depicted in Figure 2. People felt worst when they had no control and the shock was never actually delivered ($r = -.457$). The next most unpleasant scenarios were those in which people had control, yet the shock was delivered ($r = .397$), and those cases in which people had control and shock was not delivered ($r = -.308$). The least unpleasant situation was that in which people had no control and the shock was delivered ($r = -.126$). Typically, controllability was operationalized by telling subjects that shock would be contingent upon poor performance. Thus, in cases where the subject had control, yet received shock, the subject was actually receiving feedback on poor performance, which may account for the more intense ratings of unpleasantness.

Summary

We had hypothesized that having control would lead subjects to feel less stressful when confronted with a threat such as electrical shock. However, we found this to be the case only in those instances where the shock was never actually delivered. As expected, in cases where shock was threatened, but not actually delivered, subjects reported less stress when they had control. This result is consistent with the common belief that perceived control reduces stress in a threatening situation. However, in those instances where the shock was actually delivered, subjects reported more stress when they had control. This unexpected finding is probably related to the nature of the control manipulation used in the studies in this analysis. Typically, control was operationalized by telling subjects that shock would be contingent upon poor performance. Thus, in cases where the subject had control, yet received shock, the subject was actually receiving a message of failure, which may account for the higher stress reported.

TABLE 42. THREAT: CONTROL AND DELIVERY

Self-Report		Accuracy	
Controllable -- Delivered		**Controllable -- Delivered**	
$Z_{significance}$	6.950		1.275
p	< .001		.101
Z_{FISHER}	-.420		-.117
r	-.397		-.116
r^2	.158		.014
Uncontrollable -- Delivered		**Uncontrollable -- Delivered**	
$Z_{significance}$	3.957		2.784
p	< .001		.003
Z_{FISHER}	-.126		-.117
r	-.126		-.116
r^2	.016		.014
Controllable -- Not Delivered		**Controllable -- Not Delivered**	
$Z_{significance}$	6.088		3.43
p	< .001		< .001
Z_{FISHER}	-.318		-.174
r	-.308		-.172
r^2	.095		.030
Uncontrollable -- Not Delivered		**Uncontrollable -- Not Delivered**	
$Z_{significance}$	11.080		4.513
p	< .001		< .001
Z_{FISHER}	-.509		-.310
r	-.469		-.300
r^2	.220		.090

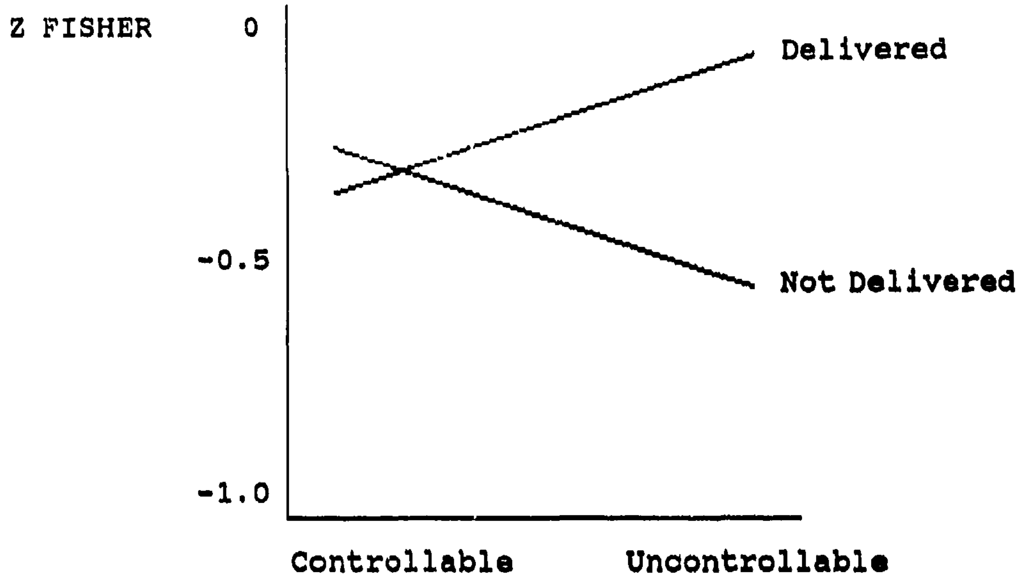

Figure 2. Interaction between controllability and delivery for self-reported stress.

General Effect of Control:

Self-Report: Control did not significantly ameliorate the negative feelings subjects reported in threatening situations.

Performance Accuracy: Control did not have an effect on performance accuracy

Effect of Control and Delivery:

Self-Report: Under conditions of uncontrollability, perceived stress and performance impairment were greater when shock was not actually delivered. Under conditions of controllability, perceived stress was greater when shock was delivered.

Accuracy: Largest impairments occurred when shock was never delivered, especially when subjects did not have control. When shock was delivered, control made no difference.

Guidelines for Manipulating Uncontrollability

One goal of this meta-analysis is to specify the effects of control on self-reported stress in order to provide the stress researcher with practical and precise guidelines for manipulating uncontrollability. These analyses show that uncontrollable shock can be used as a powerful laboratory stressor to elicit subjective stress and decrements in performance accuracy.

Greater effects are shown under conditions of anticipatory stress, when the stress is perceived as imminent, but never occurs.

Studies Included in the Meta-Analysis

Study	Hyp.	Statistic	DV	CN
Bloom, Houston, & Burish, 1976	SR	$F(1, 190) = 64.89$ (-) [192]	0	0
Burish & Hendrix, 1980	SR	$F(1, 60) = 16.66$ (-) [65]	0	0
Cox, 1983	SR	$t(94) = 4.98$ (-) [96]	1	1
Cox, 1984	SR	$t(78) = 3.19$ (-) [80]	1	1
	SR	$t(78) = 3.82$ (-) [80]	1	1
Harris, 1981	SR	$t(108) = 1.15$ (-) [80]	1	0
	SR	$t(108) = 2.57$ (-) [80]	1	0
Holmes & Houston, 1974	SR	$t(14) = 4.64$ (-) [16]	0	0
Houston, 1972(a)	SR	$t(60) = 1.84$ (-) [44]	0	1
	SR	$t(60) = 2.74$ (-) [44]	0	0
Houston & Holmes, 1974	SR	$F(1, 44) = 4.63$ (-) [48]	0	0
Houston et al., 1978	SR	$F(1, 98) = 19.83$ (-) [100]	0	0
Keinan, 1987	SR	$t(97) = 6.27$ (-) [67]	0	1
	SR	$t(97) = 6.27$ (-) [67]	0	0
Kopacz & Smith, 1971	SR	$t(54) = 3.54$ (-) [40]	0	0
	SR	$t(54) = 2.46$ (-) [40]	0	0
Landers & Martens, 1971	SR	$t(116) = 1.26$ (-) [81]	0	1
	SR	$t(116) = 3.64$ (-) [81]	0	1
Martens & Landers, 1970	SR	$t(72) = 4.875$ (-) [60]	0	1
	SR	$t(72) = 2.00$ (-) [60]	0	1
	SR	$t(152) = 4.72$ (-) [20]	0	0
	SR	$t(152) = 3.51$ (-) [20]	1	0

Study	Hyp	Statistic	DV	CN
Monat et al., 1972 Experiment 1	SR	t(152) = 1.63 (-) [20]	1	0
	SR	t(152) = 1.63 (-) [20]	1	0
Experiment 2	SR	t(216) = .39 (+) [40]	1	0
	SR	t(216) = .34 (-) [40]	1	0
	SR	t(216) = .83 (-) [40]	1	0
	SR	t(216) = 3.07 (-) [40]	1	0
Sage & Bennett, 1973	SR	t(39) = 2.30 (-) [28]	1	1
	SR	t(39) = .95 (-) [28]	1	1

Hyp.: Hypothesis. SR = self-reported stress

Statistics: (+) indicates that threat led to a more favorable self-report

(-) indicates that threat led to a more negative self-report

Numbers in brackets indicate sample size.

DV: Delivery: 1 = shock was delivered, 0 = shock was not delivered

CN: Controllability: 1 = yes, 0 = no

VIII. FATIGUE

Introduction

In a combat environment such as Operation Desert Storm, requirements for rapid deployment of a high number of sorties result in tremendous pressure on maintenance personnel to prepare and repair aircraft around-the-clock. Such uninterrupted schedules of nonstop activity are known as "continuous operations" or "CONOPS." Sometimes, individuals involved in CONOPS are required to work normal shift lengths of 7 to 12 hours and then are relieved by others while the overall operations continue. At other times, they are required to work on shifts longer than 12 hours, sometimes for days at a time, performing nonstop. Such long work stints are referred to as "sustained operations" or "SUSOPS." Naturally, such sustained work often necessitates drastically reduced sleeping time. The lack of sleep and extended work schedules that characterize SUSOPS often result in excessive fatigue. Undoubtedly, there are limits to the amount of fatigue troops can endure without great sacrifices in performance and morale. For this reason, it is desirable to derive quantitative estimates of performance and self-reported stress effects under sustained operations.

Nature and Theory of Fatigue Effects

The term "fatigue" is used in a number of different ways. Fatigue is used to describe at least three concepts:

1. physical or muscular fatigue: a decrease in performance or a need for rest due to repetitive use of the same muscle group, also termed physical exhaustion

2. mental fatigue: a decrement in performance or a need for rest due to prolonged mental activity

3. subjective fatigue: a negative feeling of physical or mental weariness or exhaustion.

It is important to distinguish between mental and physical fatigue. Studies of physical fatigue generally require prolonged or repetitive physical activity using a specific muscle group such as the "handgrip" muscles of the forearm (Johnson, 1982) or finger muscles (Ash, 1914). In contrast, while studies of mental fatigue may involve some physical activity, it does not have a repetitive, tiring nature. Although physical fatigue may occasionally be a factor in maintenance personnel exhaustion, it is more likely that mental and subjective fatigue will dominate during sustained maintenance operations.

The Cambridge Cockpit studies (Bartlett, 1943; 1953) provided major advances in analyzing mental fatigue. Subjects

sat for long periods while monitoring a variety of aircraft instrument displays and responding with aircraft controls. The subjects' skills deteriorated over time, as evidenced by a variety of measures. As the task wore on, progressively larger deviations of instrument readings were tolerated before corrective actions were taken. This trend was thought to indicate a shift in standards of performance, because the pilots felt that they were remaining as efficient as they were at the outset. The pilots also became more easily distracted (as evidenced by lapses in attention) as time passed. In addition, a restriction of cue utilization as fatigue set in was noted. Pilots began to reserve their attention for items of central importance, such as the course heading and speed indicators, while neglecting peripheral items such as the fuel gauge.

Pilots' cockpit skills also seemed to lose cohesion as time on task increased. Initially, pilots adopted a more integrated pattern of responding, but with increasing fatigue, this pattern disintegrated into separate components. Apparently, the pilots began to attend to the instruments on a sequential but isolated basis, and the appropriate control responses were no longer smoothly sequenced. Responses became more variable, especially regarding timing. Many actions, though correct, were executed at the wrong time.

A number of studies have been performed using actual military work schedules necessitating sleep loss. Drucker, Cannon, and Ware (1969) required two-man teams to operate continuously for 48 hours at a target-identification task and a compensatory tracking task. Performance suffered over time for both tasks, especially during the usual sleeping time.

Banks, Sternberg, Farrell, Debrow, and Dalhamer (1970) performed a series of sustained operation field studies, 36-to-48 hours long. Subjects performed three tasks: surveillance-target acquisition with a night-vision device, rifle firing, and grenade throwing. Performance on all three tasks was fairly stable over time. However, the surveillance task showed decrements associated with fatigue.

Ainsworth and Bishop (1971) studied four-man tank crews performing offensive, defensive, and retrograde movements for 48 hours. Crews performed communication, target surveillance, obstacle course driving, dynamic gunnery, and maintenance tasks without critical overall performance decrements. However, the researchers concluded that certain tasks (such as driving and moving surveillance) which require a protracted high level of alertness were more sensitive to sleep loss and likely to suffer degradation.

In a study by Haslam (1978), three parachute regiment platoons participated in a field study of continuous infantry operations. One platoon was deprived of sleep altogether,

another was allowed 1.5 hours of sleep, and the third was permitted three hours of sleep per 24-hour day in a nine-day exercise. A variety of measures of military performance were collected throughout the experiment, including assessments of shooting, weapon handling, digging, marching, and patrolling. Subjects also completed a daily battery of cognitive tests, which included map plotting, encoding/decoding, short-term memory, and logical reasoning. The platoon deprived of sleep was judged to be militarily ineffective after three nights without sleep. The platoon allowed 1.5 hours of sleep was deemed militarily ineffective after five nights. The platoon allowed three hours of sleep was judged to have remained effective the entire nine days.

In a related study (Haslam and Abraham, 1987), infantry soldiers were allowed no sleep for 90 hours of continuous activity, and then allowed four-hour blocks of sleep in every 24 hours for the next six days. The main effect of fatigue was mental as opposed to physical. While physical fitness did not deteriorate, mental ability and mood did. Vigilance and detailed cognitive tasks suffered the most. After three nights of sleep deprivation, performance on these tasks plummeted to 35 to 50% of control levels. Simple, well-learned tasks such as weapons handling suffered the least.

Moderators

The effects of fatigue may be moderated by a number of factors, including the number of hours of sleep deprivation, task duration, whether the task is self-paced or work-paced, the number of people in the group, and the time of day the task is performed. Each of these potential moderators will be discussed briefly below.

Hours of Sleep Deprivation. Continuous operations may require personnel to perform for extended periods (e.g., 24 or even 72 hours without sleeping). For example, in Lubin, Hord, Tracy, & Johnson (1976), Naval personnel were tested periodically over a 40-hour period. By coding each study for the time at which each testing occured, we will be able to examine the cumulative effect of sleep loss over time.

Task Duration. In some studies, subjects were required to perform a 5-minute task after a certain amount of sleep deprivation; other studies use a 20-minute task. Bills (1931) first noted that when an individual is required to sustain work and is sleep deprived, it is common to experience occasional "blocks" or "lapses" resulting in a lack of response during that period, while performance between these lapses is maintained. These lapses increase in frequency and duration as fatigue builds. Bjerner (1949) and Williams, Lubin, & Goodnow (1959) regarded such lapses as brief (from one to ten seconds) periods of sleep. If such lapses do occur and they become more frequent with increasing time on task, one would expect subjects to be

more prone to such lapses and hence, perform more poorly when performing tasks of longer duration.

Work-paced versus Self-paced Tasks. With work-paced tasks, events or machines control when a response must be made. For example, a worker on an automobile assembly line must attach parts or components at a set rate, according to how fast the partially assembled systems approach on a conveyor belt. With self-paced tasks, the individual determines when the item to be responded to appears, how long it will remain, and how much time is allotted for response. Examples of self-paced tasks are making telephone sales calls and entering data into a computer. Reaction time is crucial for work-paced tasks, but less important for self-paced tasks (Krueger, 1989). Williams et al. (1959) found that performance on work-paced tasks was more sensitive to the effects of fatigue than was performance on self-paced tasks. Thus, it may be that individuals are able to compensate more for performance lapses when they can control the pace of their own work.

Group Size. In many instances, an individual may perform a task in a relatively isolated environment; however, sustained operations involve a team task setting. The effect of others on an individual performer can have mixed effects. On one hand, it may have performance-enhancing effects related to group loyalty. Stouffer et al. (1949) found that combat soldiers identified loyalty to the group as one of the most important factors that "kept them going." It has also been suggested that the presence of others increases arousal (Zajonc, 1965; Cottrell, 1972). If this is the case, then the presence of others should improve the performance of fatigued subjects.

Conversely, others have identified a "social impairment" in performance as a result of working in the presence of others (Williams, Harkins, & Latane, 1981). In fact, the meta-analysis in Chapter III of this report revealed a strong tendency for individuals to generate a greater quantity and quality of ideas during idea-generating tasks when compared with groups. As the size of the group increased, these effects became more pronounced.

Time of Day. It has been generally established that people exhibit various predictable physiological and performance rhythms within a period of about a day--i.e., circadian rhythms (*circa dies*, about a day). Naturally, during times of continuous operations, personnel must often work hours outside the standard 8:00 a.m. to 5:00 p.m. civilian schedule. For most people, night work is problematic because it demands overriding their circadian variations. This presents a paradox for personnel expected to maintain satisfactory performance around-the-clock.

Research on time of day (Hughes and Folkard, 1976; Blake, 1967; Colquhoun, Blake, & Edwards, 1968) has shown that there is

typically a steep rise in performance from early to mid morning, and a more gradual rise to an evening peak (sometimes interrupted by a post-lunch dip), followed by a sharp decline into the normal hours of sleep.

Considering these circadian variations in performance, the effects of stressors, such as fatigue, should be most apparent at those times of the day when performance is likely to be at its worst. Conversely, the effects of fatigue should be least apparent at those times of day when performance is likely to be at its best.

The fatigue literature offers an excellent opportunity to examine time-of-day effects where they are most relevant to military concerns: how performance varies during sustained operations. The fatigue database (particularly the larger database on accuracy) lends itself nicely to this examination because, unlike the other areas, the studies within it tend to report the times of day during which measurements were taken. Therefore, we shall determine the extent to which the deleterious effects of fatigue on accuracy vary as a function of the time of day.

Procedure

Consistent with the procedure specified in Chapter II of this report, an exhaustive search was conducted to identify studies on fatigue and performance utilizing several specific search techniques. Using computer-based abstracting services, we searched the Defense Technical Information Center (DTIC), National Technical Information Service (NTIS), and PSYCHINFO databases. Using the ancestry approach, we searched the bibliographies and reference sections of obtained reports and articles to identify previous relevant studies. Using the descendency approach, we used indexing sources such as the Social Sciences Citation Index to locate relevant studies cited in earlier references. In addition, we manually searched major technical journals to identify relevant articles.

Studies were included in the meta-analysis if they reported the effect of fatigue (operationalized as sleep deprivation versus normal sleep) on performance (speed or accuracy) or self-reported stress. Studies were eliminated from consideration if the basic statistical information required for analysis was not retrievable.

We analyzed the effects of fatigue separately for three outcome measures. The first measure analyzed was performance accuracy (i.e., number of errors). The studies in the analysis yielded a total of 40 hypothesis tests for the effects of fatigue on accuracy. The second outcome measure analyzed was speed of performance. The studies in the analysis yielded 27 hypothesis tests for the effects of fatigue on speed. The third outcome

measure analyzed was self-reported stress. The studies in the analysis yielded 13 hypothesis tests for the effect of fatigue on self-reported stress. The hypothesis tests included in this meta-analysis are presented at the end of this chapter.

Results

General Effects. Table 43 presents results for 40 hypothesis tests measuring the effect of fatigue on performance accuracy. Fatigue led to a moderate ($r = -.253$) and significant ($p < .001$) decrement in accuracy.

TABLE 43. GENERAL COMBINATIONS OF SIGNIFICANCE LEVELS AND EFFECT SIZES: FATIGUE AND PERFORMANCE ACCURACY

40 Hypothesis Tests (weighted by sample size)

Combination of Significance Levels
Z for combination = 5.586
Associated one-tailed p = < .001

Fail-safe number (p = .05) = 1637

Combination of Effect Sizes
Mean Fisher's Z = -.258
Mean r = -.253
Mean r^2 = .064

Table 44 presents the results for 27 hypothesis tests measuring the effect of fatigue on performance speed. As was the case with accuracy, fatigue led to a moderate (-.294) and significant ($p <.001$) impairment of performance speed.

Table 45 presents the results for 13 hypothesis tests measuring the effect of fatigue on self-reported stress. These results indicate that the tendency for fatigue to lead to negative subjective feelings has strong magnitude ($r = -.516$) and is significant ($p <.001$).

Hours of Deprivation. Table 46 presents the correlation between Z_{FISHER} for effect size and hours of sleep deprivation for each of the three outcome measures as well as the corresponding focused comparisons of effect sizes for hours of deprivation. Interestingly, as hours of sleep deprivation increased, the decrement in performance and in the level of self-reported stress became less severe. In other words, over time, individuals still performed poorly, but they performed less poorly. One likely explanation for this result is that

TABLE 44. GENERAL COMBINATIONS OF SIGNIFICANCE LEVELS AND EFFECT SIZES: FATIGUE AND PERFORMANCE SPEED

27 Hypothesis Tests (weighted by sample size)

Combination of Significance Levels
Z for combination = 6.697
Associated one-tailed $p < .001$

Fail-safe number ($p = .05$) = 1001

Combination of Effect Sizes
Mean Fisher's Z = -.303
Mean r = -.294
Mean r^2 = .087

TABLE 45. GENERAL COMBINATIONS OF SIGNIFICANCE LEVELS AND EFFECT SIZES: FATIGUE AND SELF-REPORTED STRESS

13 Hypothesis Tests (weighted by sample size)

Combination of Significance Levels
Z for combination = 6.855
Associated one-tailed $p < .001$

Fail-safe number ($p = .05$) = 595

Combination of Effect Sizes
Mean Fisher's Z = -.571
Mean r = -.516
Mean r^2 = .266

TABLE 46. EFFECTS OF HOURS OF SLEEP DEPRIVATION

	Self-Report	Speed	Accuracy
r	.140	.339	.161
Focused Comparison			
Z	.284	2.164	1.511
p	.388	.015	.065

individuals were able to acclimate to some degree to the effects of fatigue. However, this effect was of small magnitude ($r = .140$) and far from statistical significance ($p = .388$) for self-report. For accuracy, the effect was also of small magnitude ($r = .161$), yet just shy of statistical significance ($p = .065$). In contrast, there was a moderate ($r = .339$) and significant ($p = .015$) tendency for subjects to perform less poorly over time when performance speed was the criterion.

Task Duration. Table 47 presents the correlation between Z_{FISHER} for effect size and task duration for speed and accuracy as well as the corresponding focused comparison of effect sizes for task duration. There were too few hypothesis tests in the self-report database to make reliable comparisons. There was a moderate-to-large ($r = -.408$) and significant ($p = .011$) effect in the direction of longer task durations resulting in slower performance speed. As task duration increased, performance accuracy suffered even more dramatically ($r = -.622$, $p < .001$). Figure 3 elaborates on the relationship between task duration and performance speed and accuracy. During the first 15 minutes of a task, performance speed is more affected by fatigue than performance accuracy. However, after the first 15 minutes, accuracy is more affected than speed.

TABLE 47. EFFECTS OF TASK DURATION

	Speed	Accuracy
r	-.408	-.622
Focused Comparison		
Z	2.287	5.189
p	.011	p < .001

Pacing. Table 48 presents separate combinations of significance levels and effect sizes for work-paced and self-paced tasks. The corresponding focused comparison for pacing is also given. Results are available only for the two performance measures, because there were too few hypothesis tests in the self-report database to make reliable comparisons. Fatigue led to a moderate-to-large ($r = -.360$) decrease in performance speed when the task was work-paced. When the task was self-paced, there was a significantly smaller (Z for comparison $= 1.765$, $p = .039$), yet moderate ($r = -.270$) decline in performance speed. There was a small-to-moderate impairment in performance accuracy whether the task was work-paced ($r = -.264$) or self-paced

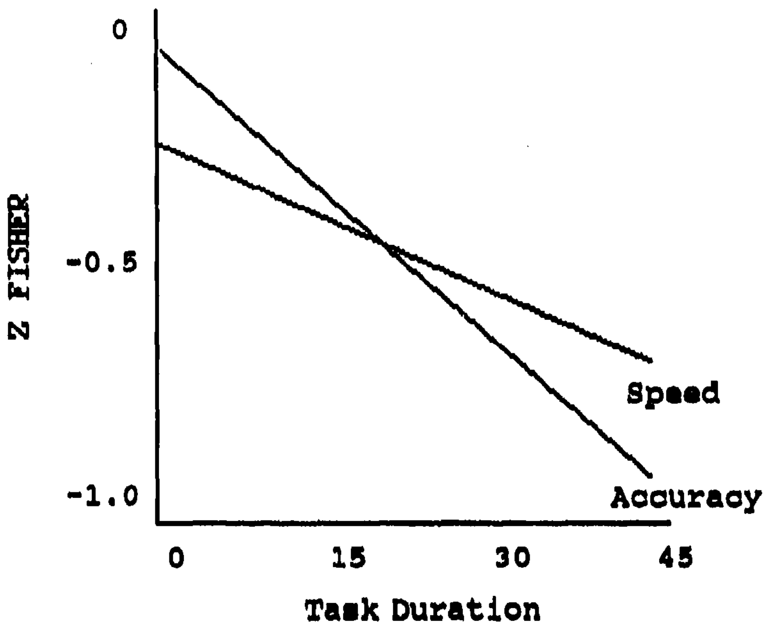

Figure 3. Effect of task duration on speed and accuracy.

($r = -.242$). The focused comparison for pacing revealed that the type of pacing makes a statistically significant difference for speed ($p = .039$), but not for accuracy ($p = .494$).

<u>Group Size</u>. Table 49 presents the correlation between Z_{FISHER} for effect size and group size for self-report, speed, and accuracy as well as the corresponding focused comparison of effect sizes for group size. Self-reported stress induced by fatigue diminished moderately ($r = .330$) as group size increased. Accuracy showed a moderate-to-large improvement ($r = .436$) as the size of the group increased. Performance speed, however, dropped moderately ($r = -.326$) with increasing group size. All three effects were statistically significant at $p < .05$.

<u>Time of Day</u>. Due to the rhythmic (nonlinear) nature of circadian effects, it was necessary to derive a nonlinear function for time of day to assess whether the effects of fatigue vary with changes in the circadian performance rhythms. A time-of-day function was derived from the work of Blake (1967), Colquhoun (1982), Compertore & Krueger (1990), Folkard (1983), Johnson (1982), and Krueger (1989). This function is presented graphically in Figure 4. Figure 4 depicts the typical pattern of rhythmic variations in human performance across time of day. While there are considerable variations in these patterns as a function of individual differences and task demands, the typical pattern is for performance to be worse around 4:00 a.m. than it

is around 12:00 p.m., with peak performance around 6:00 to 8:00 p.m.

TABLE 48. EFFECTS OF TYPE OF PACING

	Speed	Accuracy
Work-Paced		
Significance Levels		
$Z_{SIGNIFICANCE}$	4.226	3.882
p	< .001	< .001
Effect Sizes		
Z_{FISHER}	-.377	-.271
r	-.360	-.294
Self-Paced		
Significance Levels		
$Z_{SIGNIFICANCE}$	5.240	4.036
p	< .001	< .001
Effect Sizes		
Z_{FISHER}	-.277	-.247
r	-.270	-.242
Focused Comparison		
Z	1.765	.015
p	.039	.494

TABLE 49. EFFECTS OF GROUP SIZE

	Self-Report	Speed	Accuracy
r	.330	-.326	.436
Focused Comparison			
Z	1.849	1.845	4.79
p	.032	.033	< .001

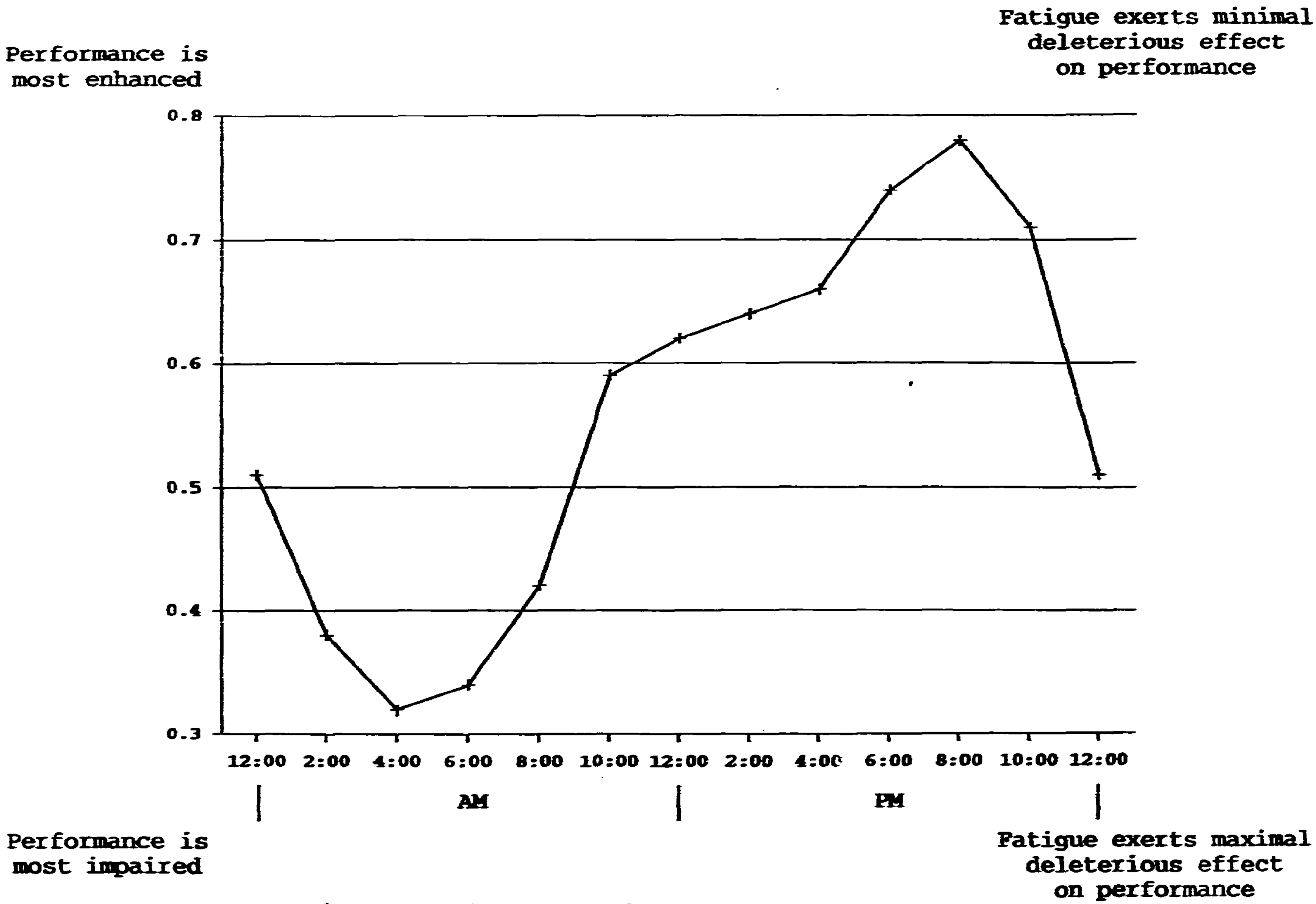

Figure 4. Effects of time of day on performance.

Table 50 presents the correlation between Z_{FISHER} for effect size and the time-of-day function for accuracy as well as the corresponding focused comparison of effect sizes for the time-of-day function. The magnitude of the effect of fatigue on accuracy of performance correlated significantly with the time-of-day function ($r = .200$, $p = .030$). Thus, the effects of fatigue are strongest when performance is typically at its lowest due to circadian rhythms. Likewise, the effects of fatigue are weakest when performance is typically at its highest due to circadian rhythms. Figure 4 illustrates when fatigue would have its minimal and maximal effects. For example, fatigue should have an extreme deleterious effect at 4:00 a.m., when performance is predicted to be at its lowest due to circadian rhythms. Conversely, fatigue should have a minimal effect on performance at 8:00 p.m., when performance is predicted to be at its highest due to circadian rhythms.

TABLE 50. EFFECTS OF TIME OF DAY

	Accuracy
r	.200
Focused Comparison	
Z	1.885
p	.030

Summary

The goal of this analysis is to specify the effects of fatigue on performance speed, performance accuracy, and self-reported stress in order to provide the stress researcher with practical and precise guidelines for manipulating fatigue. Table 51 displays the results of the general combinations of significance levels and effect sizes for the effect of fatigue on self-report, speed, and accuracy. These overall effects, as well as the results for the analyses of moderators, are briefly reviewed below.

TABLE 51. FATIGUE: SUMMARY OF OVERALL EFFECTS

	Self-Report	Speed	Accuracy
Significance Levels			
$Z_{SIGNIFICANCE}$	6.855	6.697	5.586
p	< .001	< .001	< .001
Effect Sizes			
Z_{FISHER}	-.571	-.303	-.258
r	-.516	-.294	-.253
r^2	.266	.087	.064

General Effect of Fatigue

Self-Report: There is a strong relationship between fatigue and self-reported stress.

Performance Speed: Fatigue moderately impairs performance speed.

Performance Accuracy: Fatigue moderately impairs performance accuracy.

Effect of Hours of Sleep Deprivation

Self-Report: Small, yet insignificant effect for negative self-report to be less severe with increasing hours of sleep deprivation.

Performance Speed: Moderate effect of less decrement in performance speed with increasing hours of sleep deprivation.

Performance Accuracy: Small, yet insignificant effect of less decrement in performance accuracy with increasing hours of sleep deprivation.

Effect of Task Duration

Performance Speed: Longer task durations have a moderate-to-large effect, resulting in decreased performance speed.

Performance Accuracy: Longer task durations have a very large effect, leading to diminished performance accuracy.

Effect of Type of Pacing

Performance Speed: Greater decline in performance speed with work-paced as opposed to self-paced tasks.

Performance Accuracy: No effect.

Group Size

Self-report: Self-reported stress diminished with increasing group size.

Performance Speed: Moderate drop in performance speed with increasing group size.

Performance Accuracy: Moderate-to-large improvement in performance accuracy as the size of the group increased.

Time of Day

Performance Accuracy: Effects of fatigue are strongest when circadian performance levels are lowest. Effects of fatigue are weakest when circadian performance levels are highest.

Guidelines for Manipulating Fatigue

These results suggest that fatigue is a strong and effective manipulation to impose both perceived stress and stress-related performance decrements. Table 52 shows how fatigue can be differentially manipulated to affect self-report (perceived stress), performance speed, and performance accuracy.

In order to impart the "feeling" of stress as in a confidence drill, the effect of fatigue could be maximized by limiting the hours of sleep deprivation and having the subject perform alone, as opposed to performing in a group setting. For skills training for performance speed, the effect of fatigue could be maximized by limiting the hours of sleep deprivation, increasing the duration of the task, using work-paced tasks, and having subjects perform in large groups. For skills training focusing on performance accuracy, the effects of this stressor may be fully exploited by limiting the hours of sleep deprivation, increasing the duration of the task, having subjects perform alone, and testing subjects during hours when circadian rhythms predict poorer performance.

TABLE 52. FATIGUE MANIPULATIONS FOR CONFIDENCE DRILL VERSUS SKILLS TRAINING

	Self-Report	Performance Speed	Performance Accuracy
General Effects	Strong, significant effect of fatigue on perceived stress	Moderate significant effect of fatigue on performance speed	Moderate significant effect of fatigue on performance accuracy
Hours of Deprivation	Slight, yet insignificant tendency for a stronger effect with fewer hours of deprivation	Stronger effect with fewer hours of deprivation	Slight, yet insignificant tendency for a stronger effect with fewer hours of deprivation
Task Duration	Not available	Stronger effect with increasing task duration	Stronger effect with increasing task duration
Pacing	Nct available	Stronger effect with work-paced tasks	No effect
Group Size	Stronger effect with smaller group size	Stronger effect with larger group size	Stronger effect with smaller group size
Time of Day	Not available	Not available	Stronger effect when circadian performance level is low

Studies Included in the Meta-Analysis

Study	Hyp.	Statistic	Hrs. Dep.	Task Dur.	Wk-Sf Paced	Time	GS
Bohlin & Kjellberg, 1973	SR	r(34) = .268 (-) [36]	24	NR	NR	8:00 am	1
Corcoran, 1962	AC	p = .005 (-) [16]	57	30 m	WK	3:00 pm	NR
Corcoran, 1963	AC	p = .01 (-) [19]	28	30 m	WK	10:00 am	6
	AC	p = .028 (-) [19]	58	30 m	WK	4:00 pm	6
Cutler & Cohen, 1979	SR	r(33) = .466 (-) [36]	24	12 m	NR	7:00 am	5
	AC	F(1,33) = 4.54 (-) [36]	24	3 m	SF	7:00 am	5
Edwards, 1941	AC	t(56) = .186 (+) [15]	24	3 m	WK	11:00 am	5
	AC	t(56) = .347 (+) [15]	48	3 m	WK	11:00 am	5
	AC	t(56) = .718 (-) [15]	72	3 m	WK	11:00 am	5
	AC	t(56) = 3.05 (-) [15]	96	3 m	WK	11:00 am	5
Glenville & Wilkinson, 1979	AC	F(1,11) = 9.15 (-) [12]	22	10 m	WK	4:30 am	4
	SP	F(1,11) = 10.32 (-) [12]	22	10 m	WK	4:30 am	4
	SP	F(1,11) = 12.28 (-) [12]	22	10 m	WK	4:30 am	4
Huntley & Centybear, 1974	AC	r(11) = .228 (-) [12]	29	NR	WK	NR	1
Kollar, et al., 1966	SR	r(15) = .605 (-) [4]	24	NR	NR	7:30 pm	4

Study	Hyp.	Statistic	Hrs. Dep.	Task Dur.	Wk-Sf Paced	Time	GS
Kollar, et al., 1966	SR	r(15) = .722 (-) [4]	48	NR	NR	7:30 pm	4
	SR	r(15) = .704 (-) [4]	72	NR	NR	7:30 pm	4
	SR	r(15) = .762 (-) [4]	96	NR	NR	7:30 pm	4
	SR	r(15) = .266 (-) [4]	110	NR	NR	7:30 pm	4
Lisper & Kjellberg, 1972	SP	r(7) = .665 (-) [8]	24	10 m	WK	8:15 am	2
Loveland & Williams, 1963	SP	t(38) = .699 (-) [40]	26	3 m	SF	8:00 am	2
	SP	t(38) = 1.814 (-) [40]	50	3 m	SF	8:00 am	2
	SP	t(38) = 1.860 (-) [40]	74	3 m	SF	8:00 am	2
	SP	t(38) = .387 (-) [40]	38	3 m	SF	8:00 pm	2
	SP	t(38) = 1.250 (-) [40]	62	3 m	SF	8:00 pm	2
	SP	t(38) = 1.61 (-) [40]	86	3 m	SF	8:00 pm	2
Lubin, et al., 1976	SP	t(19) = 2.755 (-) [20]	40	40 m	SF	NR	2
	SP	t(19) = 1.753 (-) [10]	40	40 m	SF	NR	2
	AC	r(19) = .846 (-) [20]	40	40 m	WK	NR	2
	AC	r(9) = .785 (-) [10]	40	40 m	WK	NR	2
	AC	t(19) = 2.281 (-) [20]	40	40 m	SF	NR	2

Study	Hyp.	Statistic	Hrs. Dep.	Task Dur.	Wk-Sf Paced	Time	GS
Lubin, et al., 1976	AC	t(9) = 3.09 (-) [10]	40	40 m	SF	NR	2
	AC	t(19) = 2.46 (-) [20]	40	NR	SF	NR	2
	AC	t(9) = 4.546 (-) [10]	40	NR	SF	NR	2
	SR	t(19) = 5.976 (-) [20]	40	NR	NR	NR	2
	SR	t(9) = 10.554 (-) [10]	40	NR	NR	NR	2
May & Kline, 1987	AC	r(108) = .005 (+) [109]	48	3.6 m	WK	2:15 pm	11
	AC	r(108) = .212 (-) [109]	48	4.8 m	SF	2:15 pm	11
May & Kline, 1988	AC	t(116) = .023 (+) [118]	72	4 m	WK	12:00 noon	grp
	AC	t(116) = .034 (-) [118]	72	4 m	SF	12:00 noon	grp
	AC	t(116) = 1.68 (+) [118]	72	4 m	SF	12:00 noon	grp
	SR	t(116) = 3.35 (-) [118]	72	4 m	NR	12:00 noon	grp
	SP	r(116) = .216 (-) [118]	72	4 m	WK	12:00 noon	grp
	SP	r(116) = .157 (-) [118]	72	4 m	SF	12:00 noon	grp
	SP	r(116) = .76 (-) [118]	72	4 m	SF	12:00 noon	grp
Mertens & Collins, 1986	SR	r(28) = .257 (-) [30]	36	10 m	NR	NR	5
	AC	r(28) = .277 (-) [30]	36	10 m	WK	NR	5
	AC	r(28) = .162 (-) [30]	36	10 m	SF	NR	5

Study	Hyp.	Statistic	Hrs. Dep.	Task Dur.	Wk-Sf Paced	Time	GS
Mertens & Collins, 1986	AC	r(28) = .343 (-) [30]	36	10 m	SF	NR	5
	AC	r(28) = .238 (-) [30]	36	10 m	WK	NR	5
	AC	r(28) = .313 (-) [30]	36	10 m	WK	NR	5
Norton, 1970	SP	t(30) = 3.997 (-) [16]	48	12.5 m	SF	12:00 noon	8
	SP	t(30) = 5.540 (-) [16]	72	12.5 m	SF	12:00 noon	8
Strausbaugh & Roessler, 1970	SP	F(1,12) = 7.73 (-) [14]	25	40 m	WK	7:30 am	grp
Webb, 1985	SP	r(16) = .458 (-) [18]	44	30 m	SF	3:00 am	grp
	SP	r(16) = .236 (-) [18]	44	20 m	SF	3:00 am	grp
	SP	r(16) = .429 (-) [18]	44	3 m	SF	3:00 am	grp
	SP	r(16) = .704 (-) [18]	44	15 m	SF	3:00 am	grp
	AC	r(16) = .388 (-) [18]	44	30 m	WK	3:00 am	grp
	AC	r(16) = .243 (-) [18]	44	20 m	WK	3:00 am	grp
	AC	r(16) = .250 (-) [18]	44	30 m	SF	3:00 am	grp
	AC	r(16) = .508 (-) [18]	44	15 m	SF	3:00 am	grp
	AC	r(16) = .218 (-) [18]	44	10 m	SF	3:00 am	grp
	SR	r(16) = .858 (-) [18]	44	4 m	NR	3:00 am	grp
Webb & Levy, 1982	SR	r(14) = .817 (-) [16]	43.5	10 m	NR	2:30 am	grp

Study	Hyp.	Statistic	Hrs. Dep.	Task Dur.	Wk-Sf Paced	Time	GS
Webb & Levy, 1982	AC	r(14) = .315 (-) [16]	43.5	30 m	WK	2:30 am	grp
	AC	r(14) = .027 (-) [16]	43.5	3 m	SF	2:30 am	grp
	SP	r(14) = .323 (-) [16]	43.5	30 m	SF	2:30 am	grp
	SP	r(14) = .247 (-) [16]	43.5	20 m	SF	2:30 am	grp
	SP	r(14) = .140 (-) [16]	43.5	3 m	SF	2:30 am	grp
Wilkinson, 1964	SP	F(1,20) = 20.9 (-) [24]	45.5	26 m	SF	4:00 am	3
Williams & Lubin, 1967	SP	r(39) = .120 (-) [40]	26	12 m	WK	8:00 am	4
	SP	r(39) = .523 (-) [40]	50	12 m	WK	8:00 am	4
Williams, et al., 1965	AC	r(23) = .369 (-) [24]	31	10 m	WK	4:15 pm	1
	AC	r(23) = .585 (-) [24]	55	10 m	WK	4:15 pm	1
	AC	r(27) = .292 (-) [28]	31	10 m	WK	4:15 pm	4
	AC	r(27) = .447 (-) [28]	55	10 m	WK	4:15 pm	4
Williams & Gieseking, 1966	AC	r(43) = .496 (-) [44]	31	NR	SF	3:00 pm	4
	AC	r(43) = .830 (-) [44]	55	NR	SF	3:00 pm	4
	AC	r(33) = .593 (+) [35]	34	NR	SF	4:00 am	4

Note:

Hyp:	Hypothesis. SR = Self-Report; AC = Accuracy; SP = Speed
Statistic:	(+) indicates fatigue improved accuracy or speed, or led to a more favorable self-report
	(-) indicates fatigue led to a decrement in accuracy or speed, or led to a more negative self-report
	Numbers in brackets represent sample size.
Hrs. Dep.:	Hours of Deprivation.
Task Dur.:	Task Duration.
Wk-Sf Paced:	Work-paced vs. Self-paced.
Time:	Time of day.
GS:	Group Size (grp indicates group size unknown)
NR:	Not Reported.

IX. DUAL TASKS

Introduction

Casual introspection suggests that we can pay attention to more than one stimulus at a time. Sometimes these are overt tasks (e.g., an air traffic controller talking to a pilot while scanning a visual display); other times they may be covert (planning, problem solving, and decision-making while scanning a visual display). Many studies show that subjects exhibit reduced performance when their attention is divided. By examining the current research on dual task performance, it may be possible to determine the effects of dual task performance as a stressor in degrading performance.

Nature and Theory of Dual-Task Effects

Most of the divided-attention and dual-task studies surveyed failed to explicitly compare a dual task with a control single-task condition. Instead, the studies simply examined the effects of various independent variables--such as task difficulty (Sullivan, 1976)--on dual task performance. Of the studies that do compare single- and dual-task performance, most focused on how the addition of a second, concurrent task affected performance on a primary task. The most prominent finding among these studies is that performing two tasks concurrently leads to a decrement in performance on the primary task (Allport, Antonis, & Reynolds, 1972; Hitch & Baddeley, 1976; Kahneman, 1975; McLeod, 1977; and Shaffer, 1975).

Two major sets of theories (structural and capacity) have been offered to explain human performance on divided attention tasks or dual tasks. These two sets of theories have been developed relatively independent of each other since the 1950s. Much of the research in this area has been based on capacity theories. The assumption within this paradigm is that there is a limited pool of attentional resources, or capacity, that can be divided across tasks. Structural theories assume that the human information processing system is parallel, capable of processing separate channels, but at some point will narrow to a serial system that must handle only one channel at a time. Thus, structural theorists are concerned with locating the "bottleneck" in human information processing. An overview of each of these theories is provided below.

Structural theorists seek to answer the question, "At what stage of processing does a parallel system, capable of processing separate channels concurrently "narrow" to a serial system that must handle one channel at a time?" Broadbent (1958) and Treisman (1969) theorized that the bottleneck occurred at the stage of perception. This idea became known as "early selection theory." In contrast, "late selection" theorists (e.g., Deutsch & Deutsch, 1963; Keele, 1973; Norman, 1968) postulated that the

bottleneck occurred at the stage at which decisions were made to initiate a response (either an overt motor response or a covert response, such as storing material in long-term memory or rehearsing it). Late selection theory assumes that a dedicated decision-making-response-selection mechanism must be available in order for an individual to perform a task.

Proponents of capacity theory argue that the concept of "attentional conflict" accounts for the deleterious effects of dual task performance. (Kahneman, 1973). "Attentional conflict" assumes that a secondary task uses some of the the attentional processing capacity formerly available for the primary task. Since attentional capacity is thought to be limited, any detraction from the resources which are available to perform the primary task will result in poorer performance on that task.

Capacity experiments typically examine how subjects' performance trades off between two tasks as task demands change. As a primary task demands more of a person's resources (i.e., becomes more difficult), fewer resources are available for a concurrent secondary task, and performance on the latter deteriorates. Thus, capacity theorists maintain that capacity can be allocated in graded quantity between separate activities. In 1967, Moray drew an analogy between human processing resources and the limited capacity of a general purpose computer, which can apply its limited capacity interchangeably to widely different classes of processing. Given such flexibility, Moray argued that it was not necessary to assume a given locus of task interference (or attentional bottleneck). The cause of interference would depend merely on the capacity demands at any particular stage of processing.

<u>Moderators</u>

The effect of dual tasks on performance may be moderated by several factors including the similarity of the two tasks (in terms of either stimuli, required processing, or response similarity) and whether subjects were allowed to practice either task before performing them concurrently.

<u>Task Similarity</u>. When one thinks of pairs of everyday activities that are performed simultaneously without difficulty, the examples that come to mind typically involve two rather dissimilar activities (talking on the phone while doodling, or reading and listening to music). There is a substantial body of research suggesting that the degree of similarity between two tasks is of great importance in determining performance in dual task schemes. Eysenck (1984) distinguished between three types of similarity: (1) similarity of stimuli involved in the task; (2) similarity of internal processing operations; and (3) similarity of responses. Eysenck posits that the similarity of processing operations is probably the most important of these

three similarities. Unfortunately, most of the research has been in areas of stimulus and response similarities.

Most of the research on stimuli similarity in dual-task performance has focused on the sense modalities to which the task stimuli are presented. It seems to be easier to continuously divide attention between two inputs in different modalities than it is to divide attention between two inputs in the same modality. For example, individuals seem to have difficulty handling two concurrent auditory inputs or two concurrent visual inputs. Allport et al. (1972) had subjects attempt to verbally shadow (repeat back) prose passages while learning auditorily presented words. Their subsequent recognition-memory performance for the words was at chance level. However, memory of the words was greatly improved when the words were presented visually. Memory was improved even more when the material to be remembered was in the form of pictures.

Treisman and Davies (1973), Eijkman and Vendrik (1965), Moore and Massaro (1973), and Tulving and Lindsay (1967) all found little or no decrement in people's accuracy in detecting simultaneous tones and lights, as compared to their accuracy in detecting only a single target. In fact, Treisman and Davis discovered that two monitoring tasks interfered with each other to a greater extent when the stimuli on both tasks were presented in the same sense modality, whether it was visual or auditory.

In an investigation by Moray and Fitter (1973), individuals were asked to press a key when a tone was heard that was either higher or louder than others in the series. Two different streams of tones were presented in two different spatial locations. Subjects were instructed to press one key when a "different" tone appeared in one location and another key when a "different" tone appeared in the other location. When a subject responded to one location, the likelihood of detecting a tone in the other location was reduced. When the two-tone detection tasks were different (i.e., one tone differed in pitch and the other in loudness), people could detect both tones as accurately as they could detect them separately.

Response similarity has also been shown to moderate performance effects on dual tasks. In a study by McLeod (1977), subjects performed a continuous-tracking task with manual responding in conjunction with a tone-identification task. Half the subjects were required to respond verbally to the tones, while the other half responded manually with the hand not involved in the tracking task. Performance on the tracking task was worse under conditions of high response similarity (manual responses on both tasks) than under low response similarity (manual responses on one task and verbal responses on the second).

Wickens (1984), Navon & Gopher (1979), and Wickens and Flach (1988) describe how tasks compete for specific processing resources within the brain itself. Wickens and Flach (1988) and Wickens (1984) presented a scheme for labeling or identifying processing resources within the brain. There are three dichotomous resource dimensions: (a) processing modalities (auditory vs. visual); (b) processing codes (verbal vs. spatial); and (c) processing stages (working memory vs. response). They assert that: (a) to the extent that two tasks share common levels on any of the three dichotomous dimensions, time-sharing will be less efficient; and (b) to the extent that an increase in resource demand occurs at the level of the dimension shared by another task, there will be increasing interference between the two. Note that the first dichotomous resource dimension is analogous to Eysenck's (1984) concept of stimuli similarity discussed above. The second two aforementioned resource components are similar to Eysenck's concept of internal processing operations. They will be described below.

The dimension of processing codes (verbal vs. spatial) distinguishes information that is mostly spatial and analog in nature from that which is verbal and linguistic. Applying the aforementioned predictions to aircraft pilots, this dichotomy suggests that a mixture of graphics and digital or verbal displays are a better format for displaying multitask information than a homogeneous display.

The dimension of processing stages distinguishes between working memory and response. Wickens (1980) reviewed data which suggested that two tasks, both demanding either response processes or perceptual or cognitive processes (e.g., decision-making, working memory, information integration), will interfere with each other to a greater extent than will a perceptual or cognitive task and a response task.

The effects of task similarity will be examined in this meta-analysis. Each set of tasks will be coded as similar or dissimilar. Tasks will be considered similar if they require the same processing modalities, codes, and stages, and dissimilar if they require different ones.

Practice. A number of studies have shown that frequently practiced tasks can be performed jointly with little interference. For example, some people have developed the ability to read and dictate simultaneously. Spelke, Hirst, and Neisser (1976) and Hirst, Spelke, Reaves, Caharack and Neisser (1980) demonstrated that with substantial practice--over 50 hours--subjects could proficiently read one text while taking dictation from a second auditorily presented text. Initially, when subjects were asked to read aloud or shadow (repeat back) prose while taking dictation, performance dropped dramatically. However, following substantial dual-task training, subjects

achieved reading and comprehension rates similar to those of the single-task control groups.

It is important to note that practice on each of two tasks performed separately does not not seem to enhance performance when those tasks are later performed concurrently. Damos, Bittner, Kennedy, and Harbeson (1981) demonstrated the need for additional dual-task practice. Subjects received 45 15-minute sessions of single-task training with a tracking task followed by practice sessions with a second concurrent tracking task. Fifteen dual-task sessions were required before dual-task performance approximated the levels obtained for single-task performance after only three single-task practice sessions.

Within the dual-task literature in this meta-analysis, we were able to assess the effect of the amount of practice on the primary task only; the second task was generally not practiced. It would seem that a secondary task would be less likely to impair performance on a well-practiced primary task. On the other hand, we might expect to find more dramatic effects of dual task performance among subjects with more practice on a primary task for a simple reason: presumably, subjects with less practice on a task are less likely to perform as well as subjects with more practice. This could set the stage for ostensibly more dramatic effects on performance with the addition of a secondary task. Performance of a secondary task may not impair primary task performance a great deal among unpracticed subjects, insofar as they are not performing that primary task well to begin with. Only among experienced, practiced subjects who are beginning to show improvement on the primary task will the introduction of the secondary task exert a dramatic impairment of performance.

Procedure

Consistent with the procedure specified in Chapter II of this report, an exhaustive search was conducted to identify studies on fatigue and performance utilizing several specific search techniques. Using computer-based abstracting services, we searched the (DTIC) and PSYCHINFO databases. Using the ancestry approach, we searched the bibliographies and reference sections of obtained reports and articles to identify previous relevant studies. Using the descendency approach, we used indexing sources such as the Social Sciences Citation Index to locate relevant studies cited in earlier references. In addition, we manually searched major technical journals to identify relevant articles.

Thirty-seven hypothesis tests were retrieved from the literature, all of which gauged the effects of dual-task performance on accuracy. The criteria for inclusion of studies in this meta-analysis were as follows:

1. The two tasks had to be performed simultaneously.
2. Both tasks had to be described in sufficient detail to understand the general nature of task performance for each task.
3. The two tasks had to be separate (e.g., pressing a button in response to an appropriate visual signal while also listening to a verbal message) rather than one actually being a subcomponent of the other task (e.g., searching an array of numbers for the string of digits "1 4 9 2" while also searching the same array of numbers for the digit "0").
4. The study had to report a meaningful test of the hypothesis that primary task performance was impaired when performing a simultaneous secondary task relative to performance on the primary task alone.

Results

General Effects. Table 53 presents the results for 37 hypothesis tests measuring the effect of the addition of a secondary task on primary task performance. The effect of dual-task performance was highly significant ($p < .001$) and of moderate magnitude ($r = .368$).

TABLE 53. GENERAL COMBINATIONS OF SIGNIFICANCE LEVELS AND EFFECT SIZES: DUAL TASK PERFORMANCE ACCURACY

37 Hypothesis Tests (weighted by sample size)

Combination of Significance Levels
Z for combination = 10.679
Associated one-tailed $p < .001$
Fail-safe number ($p = .05$) = 5128

Combination of Effect Sizes
Mean Fisher's Z = .386
Mean $r = .368$
Mean $r^2 = .135$

Task Similarity. Table 54 displays separate combinations of significance levels and effect sizes for dual-task studies in which the two tasks were similar, and for those in which they were dissimilar. The difference between the dual-task effect for the similar tasks ($r = -.413$) and the dissimilar tasks ($r = -.322$) was significant (Z for comparison = 3.653, $p < .001$). Thus, the more similar the two tasks in a dual-task paradigm, the more performance on the primary task suffered when a secondary task was added.

TABLE 54. EFFECTS OF DUAL TASK WITHIN TASK SIMILARITY

Two Similar Tasks		Two Dissimilar Tasks	
Significance Levels			
$Z_{SIGNIFICANCE}$	7.106	$Z_{SIGNIFICANCE}$	8.715
p	< .001	p	< .001
Effect Sizes			
Z_{FISHER}	-.440	Z_{FISHER}	-.334
r	-.413	r	-.322
r^2	.113	r^2	.104
Focused Comparison			
Z	3.653		
p	< .001		

Practice. Table 55 displays separate combinations of significance levels and effect sizes for dual-task studies in which the primary task was practiced, and for those in which it was not practiced. For subjects with practice on the first task, adding a second task dramatically impaired performance on the first ($r = -.580$, $p < .001$). For subjects with very little or no practice on the first task, this impairment was only small-to-moderate ($r = -.286$, $p < .001$). Thus, the dual-task impairment of primary task performance is, somewhat paradoxically, most likely to occur among subjects who are well-practiced on the primary task. This tendency was significant ($p < .001$).

Combination of Task Similarity and Practice. Table 56 displays combinations of significance levels and effect sizes for all four possible combinations of practice and task similarity. The effects of task similarity and practice combine in an additive manner: the strongest dual-task performance impairment occurred with similar task combinations and practiced primary tasks ($r = .813$). Moderate degrees of dual-task impairment occurred with dissimilar tasks and practiced subjects ($r = -.529$), and with similar tasks and unpracticed subjects ($r = -.370$). Minimal task impairment occurred in situations with dissimilar tasks and unpracticed subjects ($r = -.142$).

TABLE 55. EFFECTS OF DUAL TASK WITHIN LEVELS OF PRACTICE ON PRIMARY TASK

	Practice		No Practice
Significance Levels			
$Z_{SIGNIFICANCE}$	12.387	$Z_{SIGNIFICANCE}$	6.488
p	< .001	p	< .001
Effect Sizes			
Z_{FISHER}	-.662	Z_{FISHER}	-.294
r	-.580	r	-.286
r^2	.336	r^2	.082
Focused Comparison			
Z	3.623		
p	< .001		

TABLE 56. EFFECTS OF DUAL TASK WITHIN LEVELS OF TASK SIMILARITY AND EXPERIENCE

	No Practice/Dissimilar Tasks		No Practice/Similar Tasks
Significance Levels			
$Z_{SIGNIFICANCE}$	3.153	$Z_{SIGNIFICANCE}$	5.687
p	< .001	p	< .001
Effect Sizes			
Z_{FISHER}	-.143	Z_{FISHER}	-.388
r	-.142	r	-.370
r^2	.020	r^2	.137

	Practice/Dissimilar Tasks		Practice/Similar Tasks
Significance Levels			
$Z_{SIGNIFICANCE}$	9.395	$Z_{SIGNIFICANCE}$	14.189
p	< .001	p	< .001
Effect Sizes			
Z_{FISHER}	-.588	Z_{FISHER}	-.136
r	-.529	r	-.813
r^2	.279	r^2	.661

Summary

The goal of this analysis is to specify the effects of dual-task performance in order to provide the stress researcher with practical and precise guidelines for manipulating dual-task scenarios. These findings suggest several implications for imposing stress-related decrements via dual-task performance:

1. The largest effects of dual-task performance are evident when subjects practiced on the primary task. This is consistent with the assumption that practice only enhances performance when performed concurrently on both of the dual tasks. Thus, practice on only the primary task does not seem to enhance dual task performance, and the present results suggest that it can be detrimental.

2. Greater effects of dual-task performance are evident when the two tasks are similar. For example, an auditory signal that requires a button push response paired with an auditory signal that requires a vocal response would result in poorer performance than one auditory and one visual signal.

The findings from this meta-analysis are summarized below.

General Effect of Dual Tasks on Performance Accuracy

Secondary task moderately impairs primary task performance accuracy.

Effect of Task Similarity

Highly similar secondary task leads to greater impairment on primary task.

Effect of Practice

Practice on primary task leads to greater impairment when secondary task is added.

Guidelines for Manipulating Dual Tasks

These results indicate that adding dual tasks will serve as a strong and effective manipulation to impose stress-related impairments in performance accuracy. Table 57 shows how we would manipulate dual tasks for skills training. The effects of dual tasks can be maximized by using two highly similar tasks and having subjects practice the primary task before adding the secondary task.

TABLE 57. MANIPULATION OF DUAL TASKS FOR SKILLS TRAINING

	Performance Accuracy
General Effects	Moderate and significant effect of dual tasks on degrading performance accuracy
Task Similarity	Stronger negative effect when primary and secondary tasks are highly similar
Practice	Stronger negative effect when subjects have practiced primary task before adding secondary task

Studies Included in the Meta-Analysis

Study	Statistics	Primary	Secondary	SI	PR
Allport et al.,1972	$t(10) = 0.91$ (-) [6]	recognize visual pictures	auditory shadowing of prose	0	1
	$t(10) = 3.92$ (-) [6]	recognize visual words	auditory shadowing of prose	1	1
	$t(10) = 6.56$ (-) [6]	recognize visual words	auditory shadowing of prose	1	1
Bahrick et al.,1954	$t(68) = 4.06$ (-) [35]	press key in response to light signal	subtract numbers	0	1
	$t(68) = 3.10$ (-) [35]	press key in response to light signal	subtract numbers	0	1
	$t(68) = 2.63$ (-) [35]	press key in response to light signal	subtract numbers	0	0
	$t(68) = 2.24$ (-) [35]	press key in response to light signal	subtract numbers	0	0
Bahrick & Shelley, 1958	$t(119) = 19.56$ (-) [10]	press key in response to light signals	press key with other hand for auditory signal	1	0
	$t(119) = 13.90$ (-) [10]	press key in response to light signals	press key with other hand for auditory signal	1	1
	$t(119) = 14.07$ (-) [10]	press key in response to light signals	press key with other hand for auditory signal	1	1
Dornic,1973	$x^2_{(1)} = 4.5$ (-) [42]	recall digits and consonants presented auditorily	pursuit tracking task	0	1

Study	Statistics	Primary	Secondary	SI	PR
Hitch & Baddeley, 1976, Experiment 1	t(44) = 1.21 (-) [24]	verify sentences presented on slides	remember letters presented on slides	0	1
Hitch & Baddeley, 1976 Experiment 1	t(44) = 0.95 (+) [24]	verify sentences presented on slides	remember letters presented on slides	0	1
Experiment 2	$x^2_{(1)}$ = 0.184 (-) [24]	verify sentences presented on slides	remember letters presented on slides	0	1
Experiment 3	t(33) = 0.424 (-) [12]	verify sentences presented on slides	verbalize irrelevant material	1	1
Johnston et al.,1970, Experiment 1	t(55) = 11.33 (-) [12]	pursuit tracking task	categorize words presented auditorily	0	1
Experiment 2	t(55) = 7.49 (-) [12]	pursuit tracking task	categorize words presented auditorily	0	1
Experiment 2	t(55) = 3.91 (-) [12]	pursuit tracking task	categorize words presented auditorily	0	1
Experiment 4	t(55) = 6.16 (-) [12]	pursuit tracking task	categorize words presented auditorily	0	1
Kahneman, 1975 Experiment 1	$x^2_{(1)}$ = 2.312 (-) [122]	remember word list presented to one ear	ignore word list presented to other ear	1	1
McLeod,1977 Experiment 1	p = .002 (-) [11]	pursuit tracking task	say "hi" or "lo" to auditory tones	0	1
Experiment 1	p = .005 (-) [9]	pursuit tracking task	push "hi" or "lo" buttons to auditory tones	1	1
Experiment 1	p = .01 (-) [14]	pursuit tracking task	add/ subtract numbers	0	1

Study	Statistics	Primary	Secondary	SI	PR
Mowbray, 1953	$x^2_{(1)} = 1.216$ (-) [70]	remember written prose passages	remember passages presented auditorily	1	1
Mowbray, 1953	$x^2_{(1)} = 2.356$ (-) [70]	remember passages presented auditorily	remember written prose passages	1	1
Treisman, 1964	t(21) = 11.64 (-) [23]	shadow auditory presentation of prose	listen to irrelevant prose on unattended channel	1	1
	t(21) = 0.58 (+) [23]	shadow auditory presentation of prose	listen to irrelevant syllables on unattended channel	0	1
Williams et al., 1969 Experiment 1	t(28) = 3.99 (-) [15]	remember and write down 6 digits	copy numbers on page	1	1
Experiment 1	t(28) = 3.48 (-) [15]	remember and write down 6 digits	add pairs of digits	1	1
Experiment 1	t(28) = 5.38 (-) [15]	remember and write down 6 digits	classify digits (high & odd or low & even)	1	1
Experiment 2	t(28) = 1.08 (-) [15]	adjust lever to previous orientation	copy numbers on page	0	1
Experiment 2	t(28) = 0.43 (+) [15]	adjust lever to previous orientation	add pairs of digits	0	1
Experiment 2	t(28) = 1.03 (-) [15]	adjust lever to previous orientation	classify digits (high & odd or low & even)	0	1
Experiment 3	t(28) = 2.40 (-) [15]	adjust lever to previous orientation	match lever orientation to angle shown on page	1	1

Study	Statistics	Primary	Secondary	SI	PR
Williams et al.,1969 Experiment 3	t(28) = 2.33 (-) [15]	adjust lever to previous orientation	make specific lever movement	1	1
Experiment 4	t(28) = 0.72 (-) [15]	remember and write down 6 digits	match lever orientation to angle shown on page	0	1
Williams et al., 1969 Experiment 4	t(28) = 2.21 (-) [15]	remember and write down 6 digits	make specific lever movement	0	1

Note:

Statistics: (+) indicates that dual task performance led to improved accuracy

(-) indicates that dual task performance led to a decrement in accuracy

Numbers in brackets [ ] indicate sample size.

Primary: Description of primary task.

Secondary: Description of secondary task.

SI: Similarity. 1 = similar primary and secondary tasks; 0 = dissimilar primary and secondary tasks.

PR: Practice. 1 = practice given on primary task; 0 = no practice on primary task.

X. HEAT/COLD

Introduction

Excessive heat or cold is often problematic in operational military environments. Both heat and cold stress are sometimes a product of geographical location. Heat stress is especially troublesome because it may be exacerbated by heat produced by operating machinery or high vehicular velocity. Under many of these circumstances, it is impractical (if not impossible) to remove the excessive heat or cold from the operational environment. Therefore, it is valuable to understand what environmental limits denote the onset of performance degradation.

Nature and Theory of Temperature Effects

The effects of heat and cold on task performance are extremely complex and not well-understood from any one theoretical perspective. Generally, heat and cold are more likely to produce performance decrements in unacclimatized subjects exposed to heat or cold over a long period. A brief summary of the effects of heat and cold on performance is presented below.

Performance in Heat. Grether (1973) reviewed the research literature on a number of perceptual-motor and mental tasks (time-estimation, reaction time, tracking, and cognitive tasks) performed in elevated temperatures. He found that finger-tapping and reaction time tasks actually improved with elevated temperatures. Vigilance also improved, with an optimum at 26.7^0 C (80^0 F). Other tasks, however, showed only minor improvements up to around 29.4^0 C (85^0 F) and decrements above that level.

Research on cognitive tasks frequently demonstrates no significant relationship as a function of heat. Givoni and Rim (1962) reported no difference in performance on a dominoes task at conditions of 25^0 C (77^0 F) or 43^0 C (109^0 F). Fine, Cohen, & Crist (1960) exposed subjects to high levels of heat and humidity as they solved anagrams. They did not find performance differences in 21^0 C vs. 35^0 C (70^0 F vs. 95^0 F) conditions.

Research on heat and task performance is difficult to characterize because there are several important methodological variables that vary markedly across studies. Levels of heat and whether it is measured at core body temperature or at ambient levels, relative humidity, duration of exposure, and use of acclimatized or unacclimatized subjects all bear importantly on the relationship between heat and human performance.

Performance in Cold. The most significant effect of exposure to cold is the loss of the ability to manipulate the hands (Ramsey, 1983). Gaydos and Dusek (1958) reported a

significant decrement in manual dexterity occurring when hand-skin temperature was lowered to about 11.5° C (52.7° F). Normally, an individual required to work in the cold has a protective insulative layer of clothing. However, the hands rapidly reach a limit in terms of ability to add insulating covering since normal dexterity and general hand work is adversely affected by increased thermal insulation and protection. Loss of ability to manipulate the hands is worsened by the fact that cold leads to a loss of flexibility in the joints and in the muscles of the forearm and finger.

There is a general consensus that performance decrements in the cold are primarily a product of a deterioration in motor rather than mental capabilities. Research generally shows that cognitive or mental tasks are less affected by the cold than are motor tasks. Horvath and Freedman (1957) studied the performance of 22 men in a cold room (-30° C/20° F) for up to two weeks. Subjects showed significant performance decrements on manual and writing tasks, but mental performance was not impaired on either a code test or a visual performance test.

Moderators

The effects of heat and cold on performance may be moderated by a number of factors, including the intensity of the heat or cold environment (temperature), the type of clothing subjects wore, and the number of people in the group. Each of these potential moderators will be discussed below.

Temperature. In order to gauge the effects of temperature, all hypotheses were put on a common metric for manipulations of temperature. To begin, all temperatures were expressed in terms of dry-bulb degrees Celsius, using the standard conversion algorithms:

degrees Celsius = 5/9(degrees Fahrenheit - 32)

degrees Fahrenheit = (9/5 degrees Celsius) + 32

Then, all hypothesis tests were coded for manipulations of temperature in terms of the difference between the manipulated temperature condition and the "room temperature" condition. Thus, if a hypothesis test compared performance in room temperature (21.11° C) with performance in a room set at freezing (0° C), the temperature differential would be (0° - 21.11°) = -21.11°. Similarly, if a hypothesis test compared performance in room temperature (21.11° C) with performance set at 37.77° C (100° F), the temperature differential would be (37.77° - 21.11°) = +16.66°.

An added complexity was the variation among studies in the temperature used to establish "room temperature." The baseline "room temperature" varied between 18.33° C (65° F) and 24.44° C

(75^0 F). In an effort to compensate for these differences, the following transformations were used:

For colder temperatures:

$$\text{Temperature Differential} = (\text{Colder Temp.} - \text{Room Temp}) \times \frac{21.11}{\text{Room Temp.}}$$

For hotter temperatures:

$$\text{Temperature Differential} = (\text{Hotter Temp.} - \text{Room Temp}) \times \frac{\text{Room Temp.}}{21.11}$$

These adjustments put all hypothesis tests on the metric of comparing a hotter/colder ambient temperature with a room temperature of 21.11^0 C (70^0 F). For example, if a given hypothesis test compared performance in room temperature (21.11^0 C) with performance in a room set at freezing (0^0 C) the temperature differential would be (0 - 21.11) X (21.11/21.11) = -21.11°. However, if a given hypothesis test compared performance in a room set at freezing (0° C) with performance in a room with a lower room temperature (18.33° C), the temperature differential would be (0 - 18.33) X (21.11/18.33) = -21.08 rather than the simple temperature differential of -18.33. Thus, this adjustment essentially sets all hypothesis tests on the same metric of comparing hotter/colder ambient temperature with a room temperature of 21.11° C.

<u>Clothing</u>. Although the types of clothing that subjects wore varied from study to study, researchers standardized the attire within each study. This allowed us to look at the effects of clothing weight across studies. The clothing worn by subjects in each study was rank-ordered independently by two judges (where: 1 = maximum protection from the cold/minimal comfort in heat; and 10 = minimal protection from cold/maximum comfort in heat. For example, an ensemble of shorts and a shirt with short sleeves, was ranked high (10), whereas an ensemble of sweater, jacket, and long pants was ranked low (1). These two sets of rankings were highly reliable, with an interjudge correlation of .952, and a Spearman-Brown effective reliability of R = .975. The mean ranking for a given type of clothing was used to predict the effect of temperature manipulations.

<u>Group Size</u> Some studies of the effects of temperature on performance examined the performance of individuals working alone while others studied performance in groups of varying sizes. Group size has mixed effects on performance. Sometimes the loyalty that a larger group engenders has a positive effect on performance. At other times, groups lead to social impairment.

Within the context of studies on heat and cold, one might expect larger groups to produce a psychological illusion of

greater warmth. Thus larger group size might lead to impairments in heat, but improvements in cold.

Procedure

Consistent with the procedure specified in Chapter II of this report, an exhaustive search was conducted to identify studies on heat and cold and performance utilizing several specific search techniques. Using computer-based abstracting services, we searched the Defense Technical Information Center (DTIC) and PSYCHINFO databases. Using the ancestry approach, we searched the bibliographies and reference sections of obtained reports and articles to identify previous relevant studies. Using the descendency approach, we used indexing sources such as the Social Sciences Citation Index to locate relevant studies cited in earlier references. In addition, we manually searched major technical journals to identify relevant articles.

The criteria for inclusion of studies in this meta-analysis were as follows:

1. Manipulations of temperature were accomplished through manipulations of the temperature in a chamber surrounding the operator, rather than through simply heating or cooling a small portion of an operator's anatomy. This criterion eliminated studies that used a cold-pressor manipulation (i.e., immersion of one hand or one foot in a bucket of ice water) or the so-called "heat stressor" manipulation (i.e, the placement of hot electrodes on the subject's forearm).

2. The same task had to be performed under two different ambient temperature conditions. One temperature condition had to approximate room temperature 18.33° C (65° F) to 24.44° C (75° F). The other condition could be either colder or hotter.

3. The study had to report a meaningful test of the hypothesis that task performance was better under the room temperature than the hotter or colder temperature.

A total of 55 hypothesis tests of the effects of heat or cold were derived from the literature. Most of these tests (42) used performance accuracy as a criterion; 13 used performance speed as a criterion.

Results

General Effects of Heat. Table 58 presents results for performance speed for four hypothesis tests comparing room temperature to a hotter condition. There was a nonsignificant

($p = .289$), trivially weak ($r = .063$) tendency for subjects to respond more quickly when temperature was increased above room temperature.

TABLE 58. GENERAL COMBINATIONS OF SIGNIFICANCE LEVELS AND EFFECT SIZES: HEAT AND PERFORMANCE SPEED

---

4 Hypothesis Tests (weighted by sample size)

Combination of Significance Levels
Z for combination = .555
Associated one-tailed $p = .289$

Fail-safe number ($p = .05$) = 5

Combination of Effect Sizes
Mean Fisher's Z = .063
Mean $r = -.063$
Mean $r^2 = .004$

Table 59 presents results for performance accuracy for 31 hypothesis tests comparing room temperature to a hotter condition. There was a highly significant ($p < .001$), yet weak ($r = -.143$) tendency for subjects to respond less accurately when temperature was increased above room temperature.

TABLE 59. GENERAL COMBINATIONS OF SIGNIFICANCE LEVELS AND EFFECT SIZES: HEAT AND PERFORMANCE ACCURACY

---

31 Hypothesis Tests (weighted by sample size)

Combination of Significance Levels
Z for combination = 3.773
Associated one-tailed $p < .001$

Fail-safe number ($p = .05$) = 176

Combination of Effect Sizes
Mean Fisher's Z = -.144
Mean $r = -.143$
Mean $r^2 = .021$

General Effects of Cold. Table 60 presents results for performance speed for nine hypothesis tests comparing room temperature to a colder condition. There was a significant ($p < .001$) moderate magnitude ($r = .383$) tendency for subjects to respond more quickly when temperature was decreased below room temperature.

TABLE 60. GENERAL COMBINATIONS OF SIGNIFICANCE LEVELS AND EFFECT SIZES: COLD AND PERFORMANCE SPEED

9 Hypothesis Tests (weighted by sample size)

Combination of Significance Levels
Z for combination = .481
Associated one-tailed $p < .001$
Fail-safe number ($p = .05$) = 64

Combination of Effect Sizes
Mean Fisher's Z = -.404
Mean r = .383
Mean r^2 = .147

Table 61 presents results for performance accuracy for 11 hypothesis tests comparing room temperature to a colder condition. There was a significant ($p < .001$) moderate magnitude ($r = -.355$) tendency for subjects to respond less accurately when temperature was decreased below room temperature.

TABLE 61. GENERAL COMBINATIONS OF SIGNIFICANCE LEVELS AND EFFECT SIZES: COLD AND PERFORMANCE ACCURACY

11 Hypothesis Tests (weighted by sample size)

Combination of Significance Levels
Z for combination = 4.986
Associated one-tailed $p < .001$
Fail-safe number ($p = .05$) = 126

Combination of Effect Sizes
Mean Fisher's Z = -.371
Mean r = -.354
Mean r^2 = .126

Temperature. Table 62 presents the analysis of the effects of temperature in hot environments, including the correlation between Z_{FISHER} for effect size and temperature for speed and accuracy as well as the corresponding focused comparison of effect sizes for temperature. There was no significant tendency for variations in temperature to affect speed of response when temperature was increased above room temperature ($r = .581$, $p = .189$). There was a marginally significant tendency for hotter temperatures to produce less impairment in performance accuracy ($r = .189$, $p = .057$).

TABLE 62. EFFECTS OF TEMPERATURE IN HOT ENVIRONMENTS

	Speed	Accuracy
r	.581	.189
Focused Comparison		
Z	.540	1.584
p	.295	.057

Table 63 presents the analysis of the effects of temperature in cold environments including the correlation between Z_{FISHER} for effect size and temperature for speed and accuracy as well as the corresponding focused comparison of effect sizes for temperature. As was the case with heat, there was no significant tendency for variations in temperature to affect speed of response when temperature was decreased below room temperature ($r = -.727$, $p = .179$). However, for the hypotheses for cold effects, there was a significant tendency for colder temperatures to produce more impairment ($r = -.776$, $p < .001$) of performance accuracy.

TABLE 63. EFFECTS OF TEMPERATURE IN COLD ENVIRONMENTS

	Speed	Accuracy
r	-.727	-.775
Focused Comparison		
Z	.920	2.810
p	.179	.002

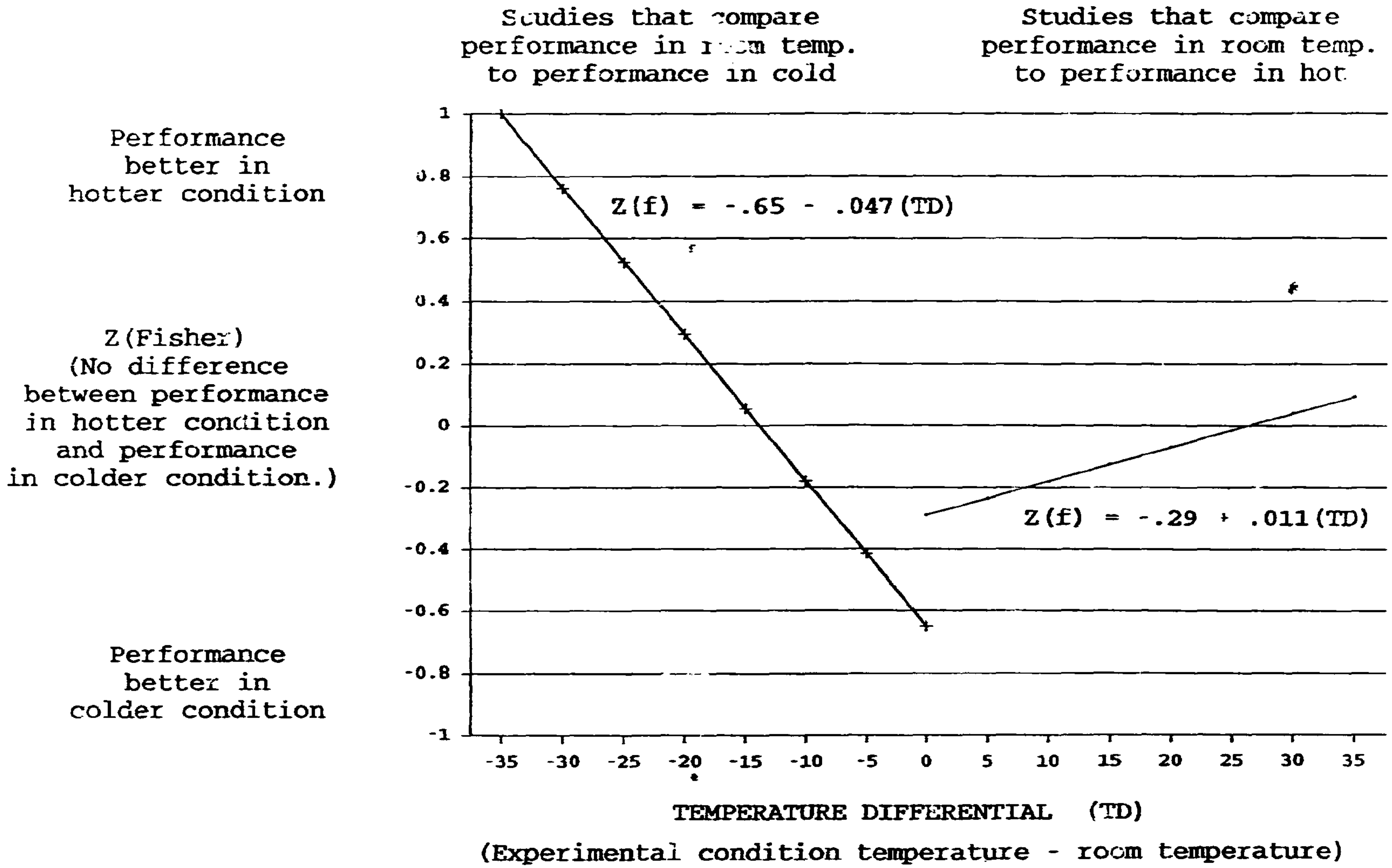

Figure 5. Effects of heat and cold on performance

There was a significant interaction between temperature differential and whether experimental temperatures were hotter or colder than room temperature (Z for comparison = 4.590, $p < .001$). This relationship is depicted in Figure 5. As reported above, when the temperature was increased above room temperature, there was a marginally significant tendency for hotter temperatures to produce less performance impairment. On the other hand, when the temperature was decreased below room temperature, there was a significant tendency for colder temperatures to produce more performance impairment.

<u>Clothing</u>. In the heat studies which assessed performance speed, all subjects wore regular clothing. Since there was no variation in clothing worn, there was no way to evaluate the effects of clothing on performance speed in heat. However, we were able to assess the effects of clothing on performance accuracy in heat. Table 64 presents the correlation between Z_{FISHER} for effect size and clothing for accuracy as well as the corresponding focused comparison of effect sizes for clothing. For those studies in which temperature was increased above room temperature, there was a significant tendency ($r = .255$, $p = .045$) for heat to impair performance accuracy less when lighter clothing was worn.

<u>TABLE 64.</u> EFFECTS OF CLOTHING IN HOT ENVIRONMENTS

	Accuracy
r	.255
Focused Comparison	
Z	1.700
p	.045

Table 65 presents the correlation between Z_{FISHER} for effect size and clothing for both speed and accuracy in cold. It also shows the corresponding focused comparison of effect sizes for clothing within those studies where temperature was decreased below room temperature. There was no significant effect ($p = .179$) of clothing on performance speed in cold. However, cold impaired performance accuracy significantly ($r = -.739$, $p < .001$) more when lighter clothing was worn.

TABLE 65. EFFECTS OF CLOTHING IN COLD ENVIRONMENTS

	Speed	Accuracy
r	-.727	-.739
Focused Comparison		
Z	.920	2.620
p	.179	.001

Table 66 displays a significant ($p < .001$) interaction between clothing and whether experimental temperatures were hotter or colder than room temperature. This indicates that the detrimental effects on performance accuracy of wearing lighter clothing in the cold are greater than the detrimental effects of wearing heavier clothing in the heat. That is, the beneficial effects of wearing heavier clothing in the cold are greater than the beneficial effects of wearing lighter clothes in the heat.

TABLE 66. INTERACTION OF COLD/HEAT AND CLOTHING

	Accuracy
r	-.406
Focused Comparison	
Z	2.779
p	<.001

Group Size. All the hypothesis tests examining the effects of heat or cold on performance speed were conducted on individual subjects. However, tests examining the effects of heat or cold on accuracy were conducted on groups varying in size from one to ten. This methodology allowed the examination of the effects of group size on the temperature effects described above. Table 67 presents the correlation between Z_{FISHER} for effect size and group size for accuracy. It also shows the corresponding focused comparison of effect sizes for group size within those studies

TABLE 67. EFFECTS OF GROUP SIZE IN HEAT

	Accuracy
r	.032
Focused Comparison	
Z	.201
p	.420

examining the effects of heat. The table shows that there was no effect for group size ($r = .032$, $p = .420$) in heat.

Table 68 presents the correlation between Z_{FISHER} for effect size and group size for accuracy as well as the corresponding focused comparison of effect sizes for group size within those studies examining the effects of cold. Among those hypothesis tests where temperature was dropped below room temperature, there was a substantial ($r = -.574$) and significant ($p < .001$) tendency for cold to impair performance less when subjects performed in groups of increasing size.

TABLE 68. EFFECTS OF GROUP SIZE IN COLD

	Accuracy
r	-.574
Focused Comparison	
Z	3.211
p	<.001

Summary

General Effect of Heat

Performance Speed: Weak and insignificant effect of heat to increase performance speed.

Performance Accuracy: Slight tendency for heat to impair performance accuracy.

General Effect of Cold

Performance Speed: Moderate and significant effect of cold to result in increased performance speed.

Performance Accuracy: Moderate and significant effect of cold to impair performance accuracy.

Effect of Temperature

Performance Speed: No effect in heat or cold.

Performance Accuracy: Stronger tendency for heat to impair performance accuracy with increasing temperature. Stronger tendency for cold to impair performance accuracy with decreasing temperature.

Clothing

Performance Speed: No effect for cold; no data available for heat.

Performance Accuracy: Heat impaired performance accuracy less when lighter clothing was worn. Cold impaired performance accuracy more when lighter clothing was worn.

Group Size

Performance Accuracy: No effect for heat. Cold impaired performance less when subjects performed in groups of increasing size.

Guidelines for Manipulating Heat and Cold

These results suggest that heat will function as an effective manipulation to impose stress-related performance decrements in performance accuracy. Cold can be manipulated to impose strong decrements in both performance speed and performance accuracy. Table 69 shows how we would differentially manipulate noise and cold to affect performance speed and accuracy.

For skills training, the negative effect of heat on performance accuracy can be maximimized by using relatively high room temperatures and having subjects wear heavy clothing. The negative effects of cold on performance accuracy can be maximized by using relatively low room temperatures, having subjects wear lighter clothing, and measuring performance of people alone or in small groups.

TABLE 69. HEAT AND COLD MANIPULATIONS FOR PERFORMANCE SPEED AND PERFORMANCE ACCURACY

	Heat		Cold	
	Peformance Speed	Performance Accuracy	Performance Speed	Performance Accuracy
General Effects	Weak, insignificant effect of heat to increase performance speed	Small tendency for heat to impair performance accuracy	Moderate, significant effect of cold to increase performance speed	Moderate, significant effect of cold to impair performance accuracy
Tempera-ture	No effect	Stronger effect with increasing temperature	No effect	Stronger effect with decreasing tempera-ture
Clothing	Not available	Stronger effect when heavier clothing is worn	No effect	Stronger effect when lighter clothing is worn
Group Size	Not available	No effect	Not available	Stronger effect with decreasing group size

Studies Included in the Meta-Analysis

Study	Hyp.	Statistics	Temperature (Centigrade)	EN	GS	CL
Aird et al., 1983	SP	t(10) = .581 (+) [6]	20.4 - 36.1	1	1	3
Bell, 1978	ACC	t(46) = 0.13 (-) [48]	22 - 29	1	1	3
	ACC	t(46) = 0.18 (-) [48]	22 - 35	1	1	3
Bell et al., 1982	SP	F(1,112) = 3.28 (-) [128]	22 - 37	1	1	3
Chiles, 1958 Experiment 1	ACC	t(20) = .669 (+) [11]	24.4 - 27.2	1	1	10
Experiment 1	ACC	t(20) = .453 (-) [11]	24.4 - 32.8	1	1	10
Experiment 1	ACC	t(20) = .130 (+) [11]	24.4 - 30	1	1	10
Experiment 2	ACC	r(18) = .316 (+) [10]	23.9 - 27.2	1	1	10
Experiment 2	ACC	r(18) = .122 (-) [10]	23.9 - 34.4	1	1	10
Experiment 2	ACC	r(18) = .054 (+) [10]	23.9 - 36.7	1	1	10
Ellis, 1982 Experiment 1	ACC	t(20) = 3.68 (+) [6]	-12 - +21.1	1	1	10
Experiment 1	ACC	t(20) = 3.83 (+) [6]	-12 - +21.1	1	1	10
Experiment 1	ACC	t(20) = 4.66 (+) [6]	-12 - +21.1	1	1	10
Experiment 1	SP	t(20) = 3.43 (-) [6]	-12 - +21.1	1	1	10
Experiment 1	SP	t(20) = 4.37 (-) [6]	-12 - +21.1	1	1	10
Experiment 1	SP	t(20) = 3.12 (-) [6]	-12 - +21.1	1	1	10
Experiment 2	ACC	t(21) = 8.03 (+) [8]	-12 - +21.1	1	1	10
Experiment 2	ACC	t(21) = 8.03 (+) [8]	-12 - +21.1	1	1	10
Experiment 2	SP	t(21) = 0.79 (-) [8]	-12 - +21.1	1	1	10
Experiment 2	SP	t(21) = 2.11 (-) [8]	-12 - +21.1	1	1	10

Study	Hyp.	Statistics	Temperatures (Centigrade)	EN	GS	CL
Ellis et al., 1985, Experiment 2	ACC	t(8) = 0.02 (+) [5]	8 - 21.1	1	1	3.5
Experiment 2	ACC	t(8) = 0.17 (+) [5]	8 - 21.1	1	1	3.5
Experiment 2	ACC	t(8) = 0.17 (-) [5]	8 - 21.1	1	1	3.5
Experiment 2	ACC	t(8) = 0.04 (+) [5]	8 - 21.1	1	1	3.5
Experiment 2	SP	t(8) = 0.57 (-) [5]	8 - 21.1	1	1	3.5
Experiment 2	SP	t(8) = 0.51 (-) [5]	8 - 21.1	1	1	3.5
Experiment 2	SP	t(8) = 0.21 (-) [5]	8 - 21.1	1	1	3.5
Experiment 2	SP	t(8) = 0.72 (-) [5]	8 - 21.1	1	1	3.5
Fine et al., 1960	ACC	t(27) = .036 (-) [10]	21/11 - 35/21	1	10	2.5
	ACC	t(27) = .863 (-) [10]	21/11 - 35/33	1	10	2.5
	ACC	t(27) = .180 (-) [10]	21/20 - 35/21	1	10	2.5
	ACC	t(27) = 1.01 (-) [10]	21/20 - 35/33	1	10	2.5
	ACC	t(27) = .537 (-) [10]	21/11 - 35/21	1	10	2.5
	ACC	t(27) = .045 (-) [10]	21/11 - 35/33	1	10	2.5
	ACC	t(27) = .268 (-) [10]	21/20 - 35/21	1	10	2.5
	ACC	t(27) = .224 (+) [10]	21/20 - 35/33	1	10	2.5
Fox et al., 1967	ACC	F(1,11) = 6.38 (-) [12]	0 - 21	1	6	7
London et al., 1968	ACC	F(1,450) = .134 (-) [32]	21 - 36.6	1	1	5.5
Lovingood et al., 1967	ACC	F(1,276) = 6.90 (+) [24]	23.3 - 52	1	1	3
	ACC	F(1,276) = 8.00 (-) [24]	23.3 - 52	1	1	3

Study	Hyp.	Statistics	Temperatures (Centigrade)	EN	GS	CL
Lovingood et al., 1967	SP	F(1,276) = 12.4 (+) [24]	23.3 - 52	1	1	3
	SP	F(1,276) = 8.48 (+) [24]	23.3 - 52	1	1	3
Pepler, 1958	ACC	t(30) = .077 (-) [16]	18.9 - 24.4	1	1	9
Pepler, 1958	ACC	t(30) = 4.0 (-) [16]	18.9 - 28.9	1	1	9
	ACC	t(30) = 4.08 (-) [16]	18.9 - 32.8	1	1	9
Teichner & Wehrkamp, 1954	ACC	t(11) = .457 (+) [13]	12.8 - 21	1	1	2.5
	ACC	t(11) = .151 (-) [13]	21 - 29.4	1	1	2.5
	ACC	t(11) = 1.116 (-) [13]	21 - 37.8	1	1	2.5
Vickroy et al., 1982	ACC	t(112) = 9.719 (-) [30]	18.3 - 25.6	1	5	1
	ACC	t(112) = 9.365 (+) [30]	18.3 - 25.6	1	5	5.5
	ACC	t(112) = 9.719 (-) [30]	18.3 - 25.6	1	5	1
	ACC	t(112) = 3.138 (+) [30]	18.3 - 25.6	1	5	5.5
Wyon, 1974	ACC	F(1,15) = 13.14 (-) [16]	20 - 24	1	4	3
	ACC	F(1,7) = 14.18 (-) [8]	20 - 24	1	4	3
	ACC	F(1,14) = 4.64 (-) [16]	20 - 24	1	4	3

Note:

Hyp.:	Hypothesis. ACC = accuracy; SP = speed
Statistics:	(+) indicates that subjects performed better in hotter condition
	(-) indicates that subjects performed better in colder condition
	Numbers in brackets [ ] indicate sample size.
Temperature:	Temperature in ^{o}C of the colder and hotter conditions.
EN:	Environment. 1 = chamber; 0 = outside environment.
GS:	Group size, or number of people.
CL:	Clothing. Ranked from 1 to 10, with 1 indicating a maximum amount of clothing and 10 indicating a minimal amount of clothing.

XI. CONCLUSIONS

This project constitutes the first comprehensive attempt to map stress effects across a wide variety of stressors through a uniform quantitative procedure. Therefore, we are in a position to examine the impact of different stressors on common outcome measures. Table 70 provides an overall matrix summarizing the effects of the different stressors on performance accuracy, performance speed, and self-reported stress.

TABLE 70. OVERALL MATRIX OF STRESSORS AND EFFECTS

	Performance Accuracy	Performance Speed	Self-Reported Stress
Noise	$r = -.140$, $p < .001$	$r = .005$, $p =$ ns	$r = -.558$, $p < .001$
Group Pressure	$r = -.558$, $p < .001$	$r = -.572$, $p < .001$	
Time Pressure	$r = -.095$, $p < .001$	$r = .304$, $p < .001$	
Threat	$r = -.160$, $p < .001$		$r = -.335$, $p < .001$
Uncontrollability			$r = -.336$, $p < .001$
Fatigue	$r = -.253$, $p < .001$	$r = -.294$, $p < .001$	$r = -.516$, $p < .001$
Dual Tasks	$r = -.368$, $p < .001$		
Heat	$r = -.143$, $p < .001$	$r = .063$, $p =$ ns	
Cold	$r = -.354$, $p < .001$	$r = .383$, $p < .001$	

Note: Mean r's have been transformed in this table so that a negative value indicates subjects performed or felt more poorly.

Table 70 presents the overall or general effects (the mean effect size (r) and associated probability level) of each stressor on each specific outcome measure. In the following, we summarize the effects of these stressors on self-reported stress, performance accuracy, and performance speed.

Column four of Table 70 presents the effects of the stressors on self-reported stress. This information is also presented graphically in Figure 6. The stressors examined tend to have a substantial effect on self-reported stress, in most cases stronger than the comparable effects on performance accuracy or speed. The stressors that impart the greatest negative subjective response are noise and fatigue; although threat and uncontrollability also produce significant and moderate-to-strong effects. Therefore, given the goal of imparting the subjective nature or the feel of a stress environment, noise, threat, uncontrollability, and fatigue are effective manipulations.

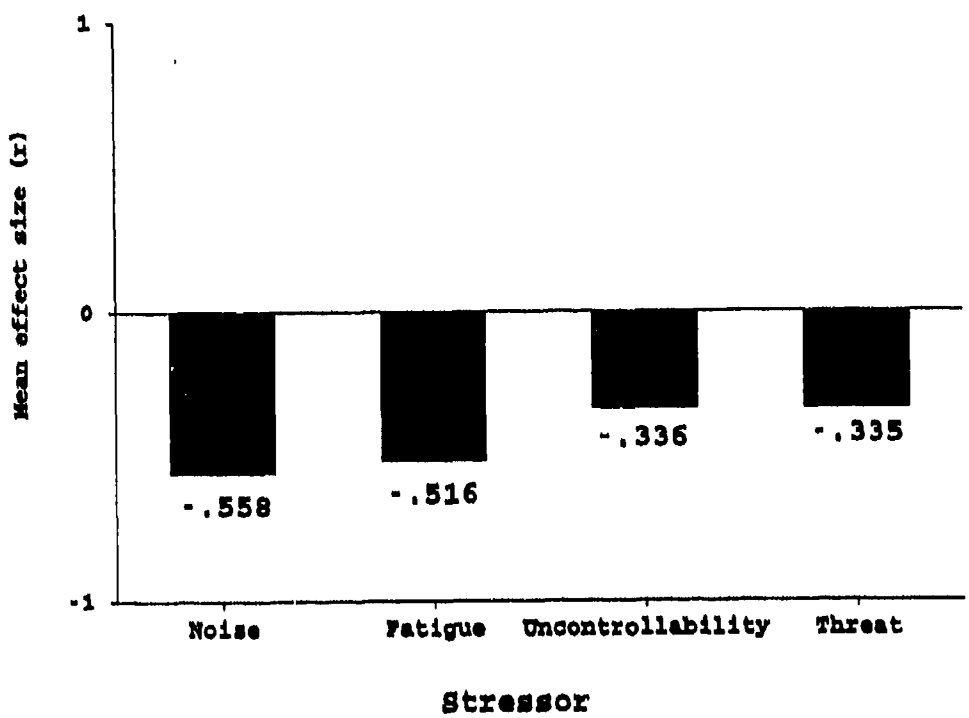

Figure 6. Effects of stressors on self-reported stress

Column two of Table 70 presents the effects of the stressors on performance accuracy. The examination of those cases in which both accuracy and self-reported stress are assessed (i.e., noise, threat, and fatigue) indicates that the effects of the stressors on performance accuracy were somewhat weaker than the effects on self-reported stress. Nevertheless, the effects of the stressors on performance accuracy were statistically significant. Plus, the general effects of group pressure, fatigue, dual tasks, and cold on performance accuracy were all of moderate-to-strong magnitude. Therefore, given the goal of inducing a stress-related decrement in performance accuracy, group pressure, fatigue, dual tasks, and cold are effective manipulations.

Figure 7 provides a summary of this data, illustrating the relative effect of each stressor on performance accuracy. The greatest impairment in accuracy was due to group pressure, followed by dual tasks, cold, fatigue, threat, heat, noise, and time pressure.

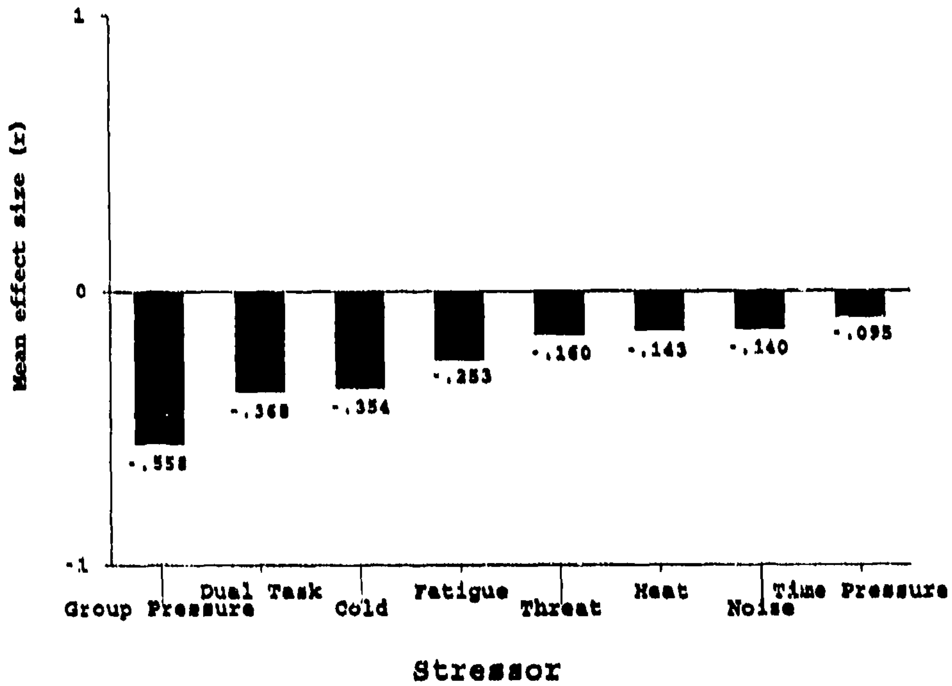

Figure 7. Effects of stressors on performance accuracy

Column three of Table 70 presents the effects of the stressors on performance speed. The general effects of stress on performance speed present a somewhat different picture than is the case with performance accuracy or self-reported stress. In most cases, the general effects of the stressors on performance

speed were of weak magnitude and in some cases, in a positive direction. Figure 8 provides a summary of this data, illustrating the relative effect of each stressor on performance speed. Figure 8 shows that group pressure and fatigue resulted in an overall decrement in performance speed; noise and heat had almost no effect on speed of performance; and time pressure and cold enhanced speed of performance.

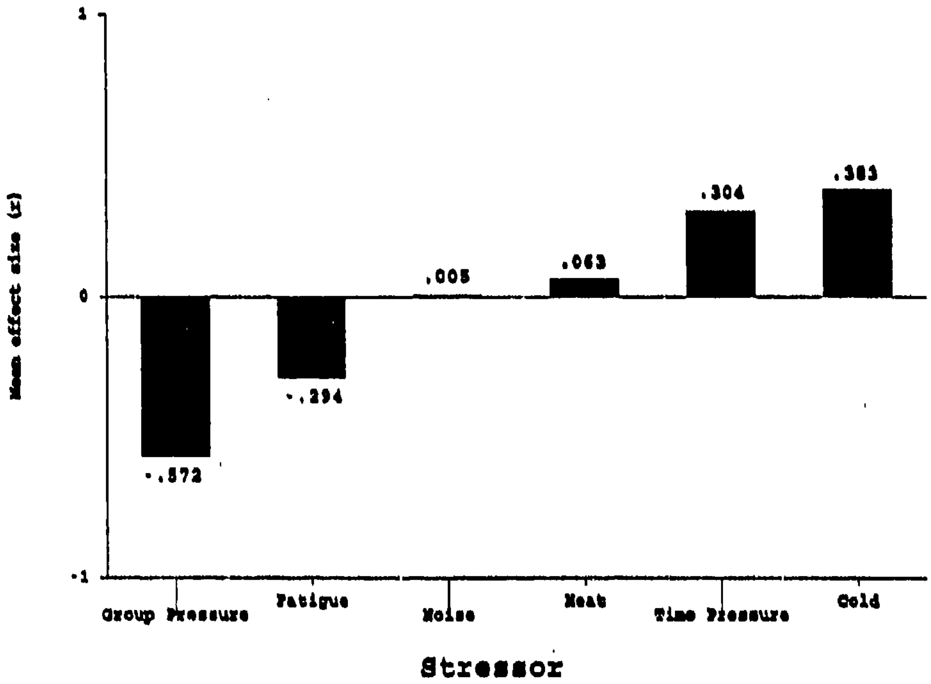

Figure 8. Effects of stressors on performance speed

In general, several overall patterns are apparent in the summary data. First, there is a generally stronger effect of these stressors on self-reported stress than on performance accuracy. Although both self-report and performance accuracy tend to be impaired by stress, people are more likely to report "feeling stressed" before showing evidence of performance impairment. This suggests that troop commanders are more likely to encounter verbal evidence of stress (i.e., subjective responses) before seeing objective evidence (i.e., performance degradation) in stressful situations.

Second, the results across stressors show evidence of a speed/accuracy tradeoff. Under noise stress, heat stress, time pressure, and cold, subjects are able to maintain performance speed with no overall degradation, but with a corresponding loss in performance accuracy. This speed/accuracy tradeoff is illustrated in Figure 9. Figure 9 indicates, for example, that cold stress results in an individual performing more quickly (a

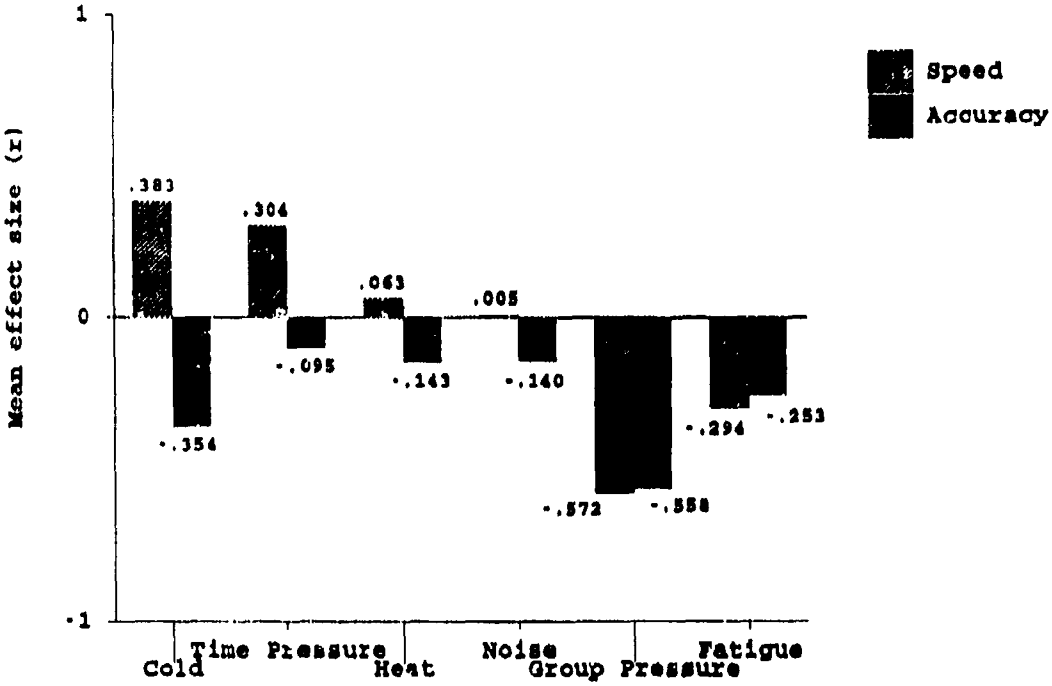

Figure 9. Speed/accuracy trade off

mean r of .383) but less accurately (a mean r of -.354). Given the apparent prevalence of the speed-accuracy tradeoff as an individual response to stress, it may be valuable to examine training interventions or other conditions under which this tendency could be altered. In other words, if individuals under stress attempt to maintain speed of performance at the cost of increased errors, this tendency may be particularly detrimental for those tasks in which effective performance is primarily determined by accuracy. For these types of tasks, we may want to examine whether individuals can be trained to overcome this tendency to trade-off accuracy for speed.

A third observation evident in Table 70 is that there are gaps in the matrix. For example, studies on group pressure and time pressure tend not to assess self-reported stress. Within these research areas, there may have been several studies in which subjective stress responses were gathered, but there were not enough cases for meaningful analysis. These gaps illustrate what we <u>don't know</u> based on this overall research integration.

In summary, Table 70 illustrates general effects across stress domains, and provides an accurate baseline to compare overall central tendencies across stressors. However, the general effect is just that--a measure of central tendency--and

does not represent ways in which we can <u>maximize</u> stressor effects. Table 71 provides an illustration of increases in stressor effects that can be gained by considering the moderators examined in each analysis.

Table 71 indicates that a considerably stronger maniplulation of time pressure can be achieved when the researcher uses continuous manipulations of time pressure with an experimenter present ($r = -.67$ versus the overall $r = -.09$). Similarly, dual tasks impose a much greater effect on performance accuracy when the tasks are similar and when practice is provided only on the primary task ($r = -.81$ versus $r = -.37$). Earlier, we noted Gardinier's (1971) frustration in attempting to find specific recommendations for manipulating noise in an effective manner. The data on general effects and moderators illustrated in Table 71 and presented in detail within each chapter provide precise guidelines for maximizing the manipulation of each particular stressor.

One moderator that was examined in most of the individual analyses was <u>intensity</u>. For noise, intensity was defined as loudness; for time pressure, intensity was defined as the extent or magnitude of time pressure; and for cold, intensity was expressed in degrees Celsius. In most cases, for self-reported stress and performance accuracy, the intensity of the stress determined the magnitude of the stress effect. In general, the greater the intensity, the greater the performance decrement. Furthermore, within the range that the stress was manipulated within each domain, this relationship was a linear function.

The fact that greater levels of stress produced greater impairment is not particularly surprising; however, these results have direct implications for the "inverted U" hypothesis. In contrast to the observed linear effect of stress on performance, the inverted U hypothesis would suggest that small levels of arousal or stress would lead to poor performance (i.e., the individual is understimulated), moderate levels of stress would lead to optimal performance, and greater levels of stress would again impair performance (the individual becomes overstimulated). We found no evidence of such an "inverted U" function in this data.

Finally, we may consider whether it is legitimate to speak of "stressor" effects in general without specification of a specific individual stressor. In a general sense, yes. Although different stressors vary in strength of effect on different outcome measures, it is generally the case that stress imparts a negative affective response, degrades performance accuracy, and has less impact on speed of performance. Furthermore, this is the first time that we are able to quantify these effects.

However, given the goal of simulating a stress environment, we consider it beneficial first to specify the objectives of that simulation. Is the objective to simulate the psychological parameters of the stress environment so people <u>feel</u> stressed? For example, one purpose of a confidence drill is for individuals

TABLE 71. STRENGTH OF EFFECT BASED ON SELECTED MODERATORS

	Performance Accuracy	Performance Speed	Self-Reported Stress
Noise	r = -.19[a]		r = -.62[b] r = -.61[c]
Group Pressure	r = -.74[d]	r = -.63[d]	
Time Pressure	r = -.67[e]		
Threat	r = -.20[f]		r = -.41[f]
Uncontrollability			r = -.46[g]
Fatigue	r = -.27[h]	r = -.38[h]	
Dual Tasks	r = -.81[i]		
Heat			
Cold			

[a] Noise presented in bursts
[b] Noise presented via headphones
[c] Noise presented in bursts
[d] Performance in presence of experimenter
[e] Continuous manipulation of time pressure with experimenter urging
[f] Anticipatory threat with threat not actually delivered
[g] Subjects reported higher stress with uncontrollable shock only when shock was not delivered
[h] Work-paced tasks
[i] Similar tasks with practice provided on the primary task

to experience the psychological ambience of a stressor environment, to master that environment, and to develop positive expectations regarding future performance. With the objective of simulating the subjective feel of the stressor environment, the outcome measure that is most relevant is self-reported stress. Therefore, stress manipulations should be chosen to impart a strong subjective response (for example, noise or threat would be good candidates).

Conversely, a different training or simulation objective may be to develop task-specific skills applicable to the stress environment. For example, the purpose of a skills training drill is to provide individuals with exposure to the performance degradation imposed by the stress environment, and then bring performance back to baseline levels through acclimation, training, or work-around techniques. With the objective of simulating the performance decrement likely to be encountered in a stress environment, the outcome measure that is most relevant is performance accuracy. Consequently, stress manipulations should be chosen to impart degradation in performance accuracy.

Further Applications

This research provides a foundation for further applications and for further research. In the following, we identify four such priority areas.

Decision Aid for Design Specifications. The military combat environment is a high stress setting. For the most part, the military training environment is not. Military training researchers continually underscore the importance of realistic training for the combat environment, especially training that incorporates stress. However, training instructors often note that they do not have the tools to conduct realistic stress training, and their request is: "Give me the information that I can use in order to conduct stress training." Similarly, the design engineer developing the specifications for a maintenance simulation or training system may acknowledge the need to incorporate stress scenarios in this system, but then ask for guidance on how to accomplish this. If the designer plans to incorporate noise as a stressor, answers must be provided regarding what type of noise, what intensity levels, how the noise should be presented, and so on.

We now have the data to answer some of these questions. However, there is a difference between data and information. Research projects often produce data; military users or design engineers often want information. The opportunity exists to take the data derived from this research program and incorporate it into an interactive computer-based decision aid to provide specific information to answer these practical questions. To provide a simple example of the value of this type of system, consider the question of how to manipulate time pressure. One of the first questions faced when implementing time pressure as a stressor in a particular scenario is how much time pressure?

Given a baseline 20 minute task, how should this task be restricted to induce an effective time pressure manipulation? In examining the effects of time pressure on performance, we derived an algorithm to predict performance effects (i.e., the extent of performance degradation) based on the magnitude of the time pressure. Based on this algorithm, we can provide a specific quantitative answer to this question according to any set criterion level. If these data are incorporated into an interactive computer-based decision aid, the user could query the system by inputting any problem (such as how to induce time pressure on a 27 minute maintenance task) and view an easily interpretable chart or graphic that shows predicted performance effects according to precise levels of time restriction. Furthermore, the system could guide the user to consider other moderators (other than intensity or magnitude) that could be implemented to increase time pressure, or to implement any other type of stressor.

One current problem in the design and acquisition of stand-alone or embedded training systems is that they are fielded without the capability to incorporate stress exercises. They are fielded this way because the design engineer cannot get precise information on stress parameters during the design phase of the system. By using this decision aid, the military researcher would be able to make informed decisions on manipulating stress, and provide precise guidelines for implementing time pressure, noise, or dual tasks. This information would constitute a significant advancement in designing stress scenarios for specific tasks.

Desktop Stress Simulator

Many of the stressors examined in this project (i.e., noise, time pressure, dual tasks) are amenable to presentation via a desktop simulator. One extension of the current research is to develop a test-bed stress simulation that would serve several purposes. First, the desktop simulator could present specific task scenarios (such as a simulated maintenance task) under conditions of varying task load, time pressure, and noise interference. The opportunity to practice tasks under conditions simulating how they may have to be performed in the operational environment provides valuable pre-exposure to the combat setting. The desktop stress simulator could run pre-programmed scenarios representing low, medium, and high stress conditions overlaid on the task, and allow the operator to perform critical tasks under more "realistic" conditions.

Second, the simulator could serve as a test-bed to evaluate hypotheses derived from the meta-analytic research. Based on the summary and integration of research within a particular domain, such as the research on time pressure, we were able to derive a number of predictions regarding the effects of time pressure on performance. Moreover, some of these findings could only have been uncovered on the basis of this meta-analytic effort. For example, only by aggregating results from a number of independent

studies could we derive an equation predicting the effects of magnitude of time pressure on performance. A subsequent task is to take these meta-analytically derived predictions and test them at the primary level of analysis; in experimental research designed to test the predictions directly. Accordingly, the desktop simulator could be used as an experimental test-bed to examine the effects of time pressure, dual tasks, threat, noise, and other stressors on performance. This test-bed could serve as a mechanism to provide very precise data on performance changes under stress conditions.

Performance Modeling. The military has developed a number of simulations or models to estimate combat performance under specified conditions. These models accept human performance parameters as input data to derive estimates of task or mission performance. In this sense, the models are only as good as the input data. Models of radiation exposure (for example, models that predict casualty rates based on extent of exposure to nuclear radiation) are based on established estimates of dosage and lethality. However, performance models rarely incorporate the effects of "psychological" stressors such as time pressure, noise, or threat, because of the lack of reliable data on stress effects. One conclusion of a recent DOD conference on combat modeling (Banks, Berghage, Kelleher, Hodgdon, & Gunderson, 1989) was that designers "have not been really interested in incorporating human factors as a broad class into these models, because we don't know where to start" (p. 262). The meta-analytic research performed in this project provides this type of data: reliable and quantitative estimates of performance degradation based on specific stress effects. The application and extension of this data to performance modeling has a potentially high payoff.

Multiple Stressors. One practical problem that arises in developing a realistic stress scenario is how to incorporate multiple stressors. For example, what are the effects of inducing noise, time pressure, and fatigue in a task setting? Most of the stressors examined in this project--noise, group pressure, time pressure, threat, uncontrollability, and dual tasks--fit the definition of acute stressors. These are environmental stressors characterized by sudden onset and relatively short duration that (a) threaten the individual's well-being and (b) tax or exceed the individual's resources. We may distinguish these types of stressors from chronic stressors: relatively long-term stressors from which effects accrue over time, such as fatigue, sleep loss, sensory deprivation, and boredom. In short, acute stressors serve to increase arousal, whereas chronic stressors decrease arousal.

When several acute stressors are present in a situation simultaneously, we would expect acute stressors to have cumulative effects according to some decreasing function. That is, the effects of noise and time pressure should be greater than the effects of noise alone. However, the effects are not directly additive; the decrement in performance attributable to

the addition of a second stressor may not be as great as that attributable to an initial stressor (in other words, time pressure may have less absolute impact on performance if the task performer is already distracted by noise interference). However, we do not clearly understand the performance effects of cumulative acute stressors such as noise pressure, dual tasks, or threat.

We understand even less the cumulative impact of acute and chronic stressors. The effects of simultaneously manipulating acute and chronic stressors may be antagonistic: Noise stress may increase arousal, and fatigue may decrease arousal. Therefore, if a fatigued operator is under-aroused, the initial impact of noise stress may be to enhance performance. Again, this area has not been clearly examined.

Based on the results of this project, we are in a unique position to examine the effects of multiple stressors. For example, we have derived quantitative estimates of the individual effects of specific stressors on performance. These can be validated in experimental research, and we can then begin to examine the effects of multiple stressors on performance. In this manner, we can examine the extent to which various types of predictive models provide accurate estimates of performance decrement from multiple stressors.

REFERENCES

Ainsworth, L. L., & Bishop, H. P. (1971). The effects of a 48-hour period of sustained field activity on tank crew performance (HumRRO TR No. 71-16). Alexandria, VA: Human Resources Research Organization.

Aird, J. W., Webb, R. D. G., & Hoare, J. (1983). Heat exposure-induced changes in motor outflow component of reaction time. Perceptual and Motor Skills, 56, 699-706.

Albery, W. B. (1988). The effects of biodynamic stress on workload in human operators. (Research Report No. AAMRL-TR-88-004). Wright-Patterson Air Force Base, OH: Harry G. Armstrong Medical Research Laboratory.

Albery, W. B. (1989). The effect of sustained acceleration and noise on workload in human operators. Aviation, Space and Environmental Medicine, 60, 943-948.

Allen, R. W., Magdaleno, R. E., & Jex, H. R. (1975). Effects of wideband auditory noise on manual control performance and dynamic response (AMRL-TR-75-65). Wright-Patterson Air Force Base, OH: Aerospace Medical Research Laboratory.

Allport, D. A., Antonis, B., & Reynolds, P. (1972). On the division of attention: A disproof of the single-channel hypothesis. Quarterly Journal of Experimental Psychology, 24, 225-235.

Ash, I. E. (1914). Fatigue and its effects upon control. Archives of Psychology, 4, 1-61.

Averill, J. R. (1973). Personal control over aversive stimuli and its relationship to stress. Psychological Bulletin, 8, 286-303.

Averill, J. R., O'Brien, L., & DeWitt, G. (1977). The influence of response effectiveness on the preference for warning and on psychophysiological stress reaction. Journal of Personality, 45, 395-418.

Averill, J. R., & Rosenn, M. (1972). Vigilant and nonvigilant coping strategies and psychophysiological stress reactions. Journal of Personality, 23, 128-141.

Bahrick, H. P., Noble, M., & Fitts, P. M. (1954). Extra-task performance as a measure of learning a primary task. Journal of Experimental Psychology, 48, 298-302.

Bahrick, H. P., & Shelly, C. (1958). Time sharing as an index of automatization. Journal of Experimental Psychology, 56, 288-293.

Banks, J. H., Sternberg, J. J., Farrell, J. P., Debrow, C. H., & Dalhamer, W. A. (1970). Effects of continuous military operations on selected military tasks (BESARL TR No. 1166). Arlington, VA: U.S. Army Organizational and Systems Research Laboratory.

Banks, W. E., Berghage, T. E., Kelleher, D. L., Hodgdon, J. A., & Gunderson, E. K. E. (1989). Proceedings of joint agency meeting on combat simulation issues (JAMCSI), 30 Nov - 1 Dec 88 (Report No. 89-8). San Diego, CA: Naval Health Research Center.

Barkowski, D., Lamm, H., & Schwinger, T. (1982). Einfallsproduction von Individuen und Dyaden unter "Brainstorming"-bedingungen. Psychologische Beitrage, 24, 39-46.

Baron, R. S. (1978). Aggression and heat: "The long hot summer" revisited. In A. Baum, J. Singer & S. Valins (Eds.), Advances in environmental psychology (Vol. 1, pp. 57-84). Hillsdale, NJ: Erlbaum.

Baron, R. S. (1986). Distraction-conflict theory: Progress and problems. In L. Berkowitz (Ed.), Advances in experimental social psychology (Vol. 19, pp. 1-40). New York: Academic Press.

Bartlett, F. C. (1943). Fatigue following highly skilled work. Proceedings of the Royal Society, Series B, 131, 247-257.

Bartlett, F. C. (1953). Psychological criteria of fatigue. In W. F. Floyd, & A. T. Welford (Eds.), Symposium on fatigue (pp. 1-5). London: H. K. Lewis & Company.

Batchelor, C. (1988). Impact of stress on combat maintenance organizations. Proceedings of the 11th symposium, Psychology in the Department of Defense. Colorado Springs, CO: United States Air Force Academy.

Baum, A., & Paulus, P. (1987). Crowding. In D. Stokols & I. Altman (Eds.), Handbook of environmental psychology (pp. 533-570). New York: Wiley.

Baumeister, R. F. (1984). Choking under pressure: Self-consciousness and paradoxical effects of incentives on skillful performance. Journal of Personality and Social Psychology, 46, 610-620.

Bell, P. A. (1978). Effects of noise and heat stress on primary and subsidiary task performance. Human Factors, 20, 749-752.

Bell, P., & Greene, T. (1982). Thermal stress: physiological comfort, performance, and social effects of hot and cold environments. In G. W. Evans (Ed.), Environmental Stress. New York: Cambridge University Press.

Bell, P. A., Loomis, R. J., & Cervone, J. C. (1982). Effects of heat, social facilitation, sex differences, and task difficulty on reaction time. Human Factors, 24, 19-24.

Benor, D. and Shvartz, E. (1971). Effect of body cooling on vigilance in hot environments. Aerospace Medicine, 42, 727-730.

Bergstrom, B. (1970). Manual missile guidance under short-term psychological stress: A literature review. (MPI Reports I). Stockholm: Institute of Military Psychology.

Berkun, M., Bialek, H., Kern, R., & Yagi, K. (1962). Experimental studies of psychological stress in man. Psychological Monographs, 76 (15).

Bills, A. G. (1931). Blocking: A new principle in mental fatigue. American Journal of Psychology, 43, 230-245.

Bingham, D., & Hailey, B. J. (1989). The time urgency component of the Type A behavior pattern: Time pressure and performance. Journal of Applied Social Psychology, 19, 425-432.

Bjerner, B. (1949). Alpha depression and lowered pulse rate during delayed actions in a serial reaction test: A study in sleep deprivation. Acta Physiologica Scandinavica, 19, Supplement 65.

Blake, M. J. F. (1967). Time of day effects on performance in a range of tasks. Psychonomic Science, 9, 349-350.

Bloom, L. J., Houston, B. K., & Burish, T. G. (1976). An evaluation of finger pulse volume as a psychophysiological measure of anxiety. Psychophysiology, 13, 40-42.

Boggs, D. H., & Simon, R. S. (1968). Differential effect of noise on tasks of varying complexity. Journal of Applied Psychology, 52, 148-153.

Bohlin, G., & Kjellberg, A. (1973). Self-reported arousal during sleep deprivation and its relation to performance and physiological variables. Scandanavian Journal of Psychology, 14, 78-86.

Bouchard, T. J., Drauden, G., & Barsaloux, J. (1974). A comparison of individual, subgroup, and total group methods of problem solving. Journal of Applied Psychology, 59, 226-227.

Bouchard, T. J., & Hare, M. (1970). Size, performance, and potential in brainstorming groups. Journal of Applied Psychology, 54, 51-55.

Bowers, K. (1968). Pain, anxiety, and perceived control. Journal of Clinical and Consulting Psychology, 32, 596-602.

Broadbent, D. E. (1953). Noise, paced performance and vigilance tasks. British Journal of Psychology, 44, 295-303.

Broadbent, D. E. (1957). Effects of noises of high and low frequency on behavior. Ergonomics, 1, 21-29.

Broadbent, D. E. (1958). Perception and communication. London: Pergamon.

Broadbent, D. E. (1971). Decision and stress. New York: Academic Press.

Burger, J. M., & Arkin, R. (1980). Prediction, control, and learned helplessness. Journal of Personality and Social Psychology, 38, 482-491.

Burish, T. G., & Hendrix, E. M. (1980). Importance of relaxation instructions in the EMG biofeedback training package. Journal of Psychosomatic Research, 24, 137-145.

Burke, W. P. (1980). Development of predictors of performance under stress in Jumpmaster training (Research Report No. 1352). Ft. Benning, GA: U.S. Army Research Institute.

Campbell, J. (1983). Ambient stressors. Environment and Behavior, 15, 355-380.

Carron, A. V. (1968). Motor performance under stress. Research Quarterly, 29, 463-469.

Carver, C. S., Blaney, P. H., & Scheier, M. F. (1979). Focus of attention, chronic expectancy, and responses to a feared stimulus. Journal of Personality and Social Psychology, 37, 1186-1195.

Carver, C. S., & Scheier, M. F. (1981). Attention and self-regulation: A control theory approach to human behavior. New York: Springer Verlag.

Casey, J. T., Gettys, C. F., & Pliske, R. M. (1984). A partition of small group predecision performance into informational and social components. Organizational Behavior and Human Performance, 34, 112-139.

Cassell, E. E., & Dallenbach, K. M. (1918). The effect of auditory distraction upon the sensory reaction. American Journal of Psychology, 29, 129-143.

Champion, R. A. (1950). Studies of experimentally induced disturbance. Australian Journal of Psychology, 2, 90-99.

Chiles, D. (1958). Effects of elevated temperatures on performance of a complex mental task. Ergonomics, 2, 89-96.

Coates, G. D., & Alluisi, E. A. (1975). A review and preliminary evaluation of methodological factors in performance assessments of time-varying aircraft noise effects. Hampton, VA: National Aeronautics and Space Administration, Langley Research Center.

Cohen, J. (1977). Statistical power analysis for the behavioral sciences (2nd ed.). New York: Academic Press.

Cohen, S. (1980). Aftereffects of stress on human performance and social behavior: A review of research and theory. *Psychological Bulletin*, *88*, 82-108.

Cohen, H. H., Conrad, D. W., O'Brien, J. F. & Pearson, R. G. (1974). *Effects of noise upon human information processing* (Research Report No. NASA CR-132469). Washington, DC: National Aeronautics and Space Administration.

Cohen, S., Evans, G. W., Krantz, D. S., & Stokols, D. (1980). Physiological, motivational, and cognitive effects of aircraft noise on children: Moving from the laboratory to the field. *American Psychologist*, *35*, 231-243.

Cohen, S., Evans, G. W., Krantz, D. S., & Stokols, D. (1981). Aircraft noise and children: Longitudinal and cross sectional evidence on adaptation to noise and the effectiveness of noise abatement. *Journal of Personality and Social Psychology*, *40*, 331-345.

Cohen, S., Evans, G. W., Stokols, D., & Krantz, D. S. (1986). *Behavior, health, and environmental stress*. New York: Plenum.

Cohen, S., & Weinstein, N. (1981). Nonauditory effects of noise on behavior and health. *Journal of Social Issues*, *37*, 36-70.

Cohen, D., Whitmyre, J. W., & Funk, D. W. (1960). Effect of group cohesiveness and training upon creative thinking. *Journal of Applied Psychology*, *44*, 319-322.

Colquhoun, W.P. (1982). Biological rhythms and performance. In W. B. Webb (Ed.), *Biological rhythms, sleep, and performance* (pp. 59-86). New York: Wiley.

Colquhoun, W. P., Blake, M. J. F., & Edwards, R. S. (1968). Experimental studies of shift work. 1: A comparison of rotating and stabilized 4 hour shift systems. *Ergonomics*, *11*, 437-453.

Combs, A. W., & Taylor, C. (1952). The effect of the perception of mild degrees of threat on performance. *Journal of Abnormal and Social Psychology*, *47*, 420-424.

Comperatore, C. A., & Krueger, G. P. (1990). *Circadian rhythm desynchronosis, jet lag, shift lag, and coping strategies* (Report No. 90). Fort Rucker, Alabama: United States Army Aeromedical Research Laboratory.

Conrad, D. W. (1973). The effects of intermittent noise on human serial decoding performance and physiological response. *Ergonomics*, *16*, 739-747.

Coomler, J. (1985). *Causes of combat stress in the artillery firing battery supporting high-intensity conflict in the European theatre*. Ft. Leavenworth, KS: U.S. Army Command and General Staff College (AD-A167674).

Cooper, H. M. (1984). The integrative research review: A social science approach. Beverly Hills, CA: Sage.

Corah, N. L., & Boffa, J. (1970). Perceived control, self-observation, and response to aversive stimulation. Journal of Personality and Social Psychology, 16, 1-4.

Corcoran, D. W. J. (1962). Noise and loss of sleep. Quarterly Journal of Experimental Psychology, 14, 178-182.

Corcoran, D. W. J. (1963). Doubling the rate of signal presentation in a vigilance task during sleep deprivation. Journal of Applied Psychology, 47, 412-415.

Cottrell, N. B. (1972). Social facilitation. In C. G. McClintock (Ed.), Experimental social psychology (pp. 185-236). New York: Holt.

Coulter, X. (1970). The effects of performance relevance and feedback upon resistance to anticipatory stress. (Rept. No. NAMRL 1114). Pensacola, FL: Naval Aerospace Medical Research Laboratory.

Cox, R. H. (1983). Consolidation of pursuit rotor learning under conditions of induced arousal. Research Quarterly for Exercise and Sport, 54(3), 223-228.

Cox, R. H. (1984). Consolidation of pursuit rotor learning under conditions of threat of electrical shock. International Journal of Sports Psychology, 15, 1-10.

Cutler, N. R., & Cohen, H. B. (1979). The effect of one night's sleep loss on mood and memory in normal subjects. Comprehensive Psychiatry, 20, 61-66.

Daee, S., & Wilding, J. M. (1977). Effects of high intensity white noise on short-term memory for position in a list and sequence. British Journal of Psychology, 68, 335-349.

D'Amato, M. E., & Gumenik, W. E. (1970). Some effects of immediate versus randomly delayed shock on an instrumental response and cognitive processes. Journal of Abnormal and Social Psychology, 16, 1-4.

Damos, D. L., Bittner, A. C., Kennedy, R. S., & Harbeson, M. M. (1981). Effects of extended practice on dual-task tracking performance. Human Factors, 23, 627-631.

Danev, S. G., de Winter, C. R., & Wartna, G. F. (1972). Information processing and psychophysiological functions in a task with and without time stress. Activitas Nervosa Superior, 14, 8-12.

Davies, A. D., & Davies, D. R. (1975). The effects of noise and time of day upon age differences in performance at two checking tasks. Ergonomics, 18, 321-336.

Davies, D. R., & Hockey, G. R. J. (1966). The effects of noise and doubling signal frequency on individual differences in visual vigilance performance. British Journal of Psychology, 57, 381-389.

Deutsch, J. A., & Deutsch, D. (1963). Attention: Some theoretical considerations. Psychological Review, 70, 80-90.

Diehl, M., & Stroebe, W. (1987). Productivity loss in brainstorming groups: Toward the solution of a riddle. Journal of Personality and Social Psychology, 53, 497-509.

Dillon, P. C., Graham, W. K., & Aidells, A. L. (1972). Brainstorming on a "hot" problem: Effects of training and practice on individual and group performance. Journal of Applied Psychology, 47, 30-37.

Donnerstein, E., & Wilson, D. W. (1976). Effects of noise and perceived control on ongoing and subsequent aggressive behavior. Journal of Personality and Social Psychology, 34, 774-781.

Dornic, S. (1973). Order error in attended and nonattended tasks. In S. Kornblum (Ed.), Attention and Performance Vol. IV. London: Academic Press.

Driskell, J. E. (1984). Training for a hostile environment. Paper presented at the annual meeting of the American Psychological Association, Toronto.

Driskell, J. E. (1986). Human performance in hostile environments. In A. Smode (Ed.), Independent research annual report (Technical Report 85-003). Orlando, FL: Naval Training Systems Center.

Driskell, J. E., Moskal, P., & Carson, R. (1987). Stress and human performance (Technical Report 86-022). Orlando, FL: Naval Training Systems Center.

Driskell, J. E., & Olmstead, B. (1989). Psychology and the military: Research applications and trends. American Psychologist, 44, 43-54.

Driskell, J. E., & Salas, E. (1991). Overcoming the effects of stress on military performance: Human factors, training, and selection strategies. In R. Gal & A. Mangelsdorff (Eds.), Handbook of military psychology (pp. 183-193). London: Wiley.

Drucker, E. H., Cannon, L. D., & Ware, J. R. (1969). The effects of sleep deprivation on performance over a 48-hour period (HumRRO TR No. 69-8). Alexandria, VA: Human Resources Research Organization.

Druckman, D., & Swets, J. (1988). Enhancing human performance. Washington, DC: National Academy Press.

Dunnette, M. D., Campbell, J., & Jaastad, K. (1963). The effect of group participation on brainstorming effectiveness for two industrial samples. Journal of Applied Psychology, 47, 30-37.

Easterbrook, J. A. (1959). The effect of emotion on cue utilization and the organization of behavior. Psychological Review, 66, 183-201.

Edwards, A. S. (1941). Effects of the loss of one hundred hours of sleep. American Journal of Psychology, 54, 80-91.

Eijkam, E., & Vendrik, A. J. H. (1965). Can a sensory system be specified by its internal noise? Journal of the Acoustical Society of America, 37, 1102-1109.

Ellis, H. D. (1982). The effects of cold on the performance of serial choice reaction time and various discrete tasks. Human Factors, 24, 589-598.

Ellis, H. D., Wilcox, S. E., & Zaman, S. A. (1985). Cold and performance: The effects of information load, analgesics, and the rate of cooling. Aviation, Space, and Environmental Medicine, 233-237.

Epstein, Y. (1982). Crowding stress and human behavior. In G. W. Evans (Ed.), Environmental stress. New York: Cambridge University Press.

Eschenbrenner, A. J. (1971). Effects of intermittent noise on the performance of a complex psychomotor task. Human Factors, 13, 59-63.

Evans, G. W., & Cohen, S. (1987). Environmental stress. In D. Stokols & I. Altman (Eds.), Handbook of Environmental Pyschology (pp. 571-610). New York: John Wiley & Sons.

Evans, G. W., & Jacobs, S. V. (1982). Air pollution and human behavior. In G. W. Evans (Ed.), Environmental Stress. New York: Cambridge University Press.

Eysenck, M. W. (1982). Attention and arousal: Cognition and performance. Berlin: Springer.

Eysenck, M. W. (1984). Attention and performance limitations. In M. W. Eysenck (Ed.), A handbook of cognitive psychology (pp. 49-75). London: Erlbaum.

Farmer, E. W., Hunter, J., & Belysvin, A. J. (1984). Performance under time constraint: The role of personality. Perceptual and Motor Skills, 59, 875-884.

Fine, B. J., Cohen, A., & Crist, B. (1960). Effects of exposure to high humidity and moderate ambient temperatures on anagram solution and auditory discrimination. Psychological Reports, 7, 171.

Finkelman, J. M., Zeitlin, L. R, Filippi, J. A., & Friend, M. A. (1977). Noise and driver performance. Journal of Applied Psychology, 62, 713-718.

Finkelman, J. M., Zeitlin, L. R., Romoff, R. A., Friend, M. A., & Brown, L. S. (1979). Conjoint effect of physical stress and noise stress on information processing performance and cardiac response. Human Factors, 21, 1-6.

Fischl, M. A., Siegel, A. I., & Macpherson, D. H. (1966). Studies into information presentation through novel methods. Fort Monmouth, NJ: U.S. Army Electronics Command. (AD635693).

Fisher, R. A. (1932). Statistical methods for research workers (4th ed.). London: Oliver and Boyd.

Fisher, R. A. (1938). Statistical methods for research workers (7th ed.). London: Oliver and Boyd.

Folkard, S. (1983). Diurnal variation. In G. R. J. Hockey (Ed.), Stress and fatigue in human performance (pp. 245-272). New York: Wiley.

Fornwalt, N. E. (1965). Investigation into the effect of intermittent noise of constant periodicity vs. random periodicity on the performance of an industrial task. Unpublished master's thesis, Texas Tech College. (NTIS No. AD-611788)

Foushee, H. C. (1984). Dyads and triads at 35,000 feet. Factors affecting group process and aircrew performance. American Psychologist, 39, 885-893.

Fowler, C. J. H., & Wilding, J. (1979). Differential effects of noise and incentives on learning. British Journal of Psychology, 70, 149-153.

Fox, R. H., Bradbury, P. H., Hampton, I. F. G., & Legg, C. F. (1967). Time judgment and body temperature. Journal of Experimental Psychology, 75(1), 88-96.

Fraser, D. C. (1953). The relation of an environmental variable to performance in a prolonged visual task. Quarterly Journal of Experimental Psychology, 5, 31-32.

French, B. A. (1983). Some effects of stress on users of a voice recognition system: A preliminary inquiry. Monterey, CA: Naval Postgraduate School. (AD-A128559)

Friedland, N., & Keinan, G. (1986). Stressors and tasks: How and when should stressors be introduced during training for task performance in stressful situations? Journal of Human Stress, 71-76.

Friedman, L. (1981). How affiliation affects stress in fear and anxiety situations. Journal of Personality and Social Psychology, 40, 1102-1117.

Gardinier, C. A. (1971). A study of the effects of illumination and noise on simple motor performance. Unpublished master's thesis, Texas A & M University.

Gardner, G. T. (1978). Effects of federal human subjects regulations on data obtained in environmental stressor research. Journal of Personality and Social Psychology, 36, 628-634.

Gaydos, H. F., & Dusek, E. R. (1958). Effects of localized hand cooling versus total body cooling on manual performance. Journal of Applied Physiology, 12, 377-380.

Geen, R. G., & Bushman, B. J. (1987). Drive theory: Effects of socially engendered arousal. In B. Mullen & G. R. Goethals (Eds.), Theories of group behavior. New York: Springer-Verlag.

Geer, J. H., Davidson, G. C., & Gatchel, R. I. (1970). Reduction of stress in humans through nonveridical perceived control of aversive stimulation. Journal of Personality and Social Psychology, 16, 731-738.

Givoni, R., & Rim, Y. (1962). Effects of the thermal environment and psychological factors upon the subject's responses and performance of mental work. Ergonomics, 5, 99-114.

Glass, G. (1976). Primary, secondary and meta-analysis of research. Educational Research, 5, 351-379.

Glenville, M., & Wilkinson, R. T. (1979). Portable devices for measuring performance in the field: The effects of sleep deprivation and night shifts on the performance of computer operators. Ergonomics, 22, 927-933.

Goh, D. S., & Farley, F. H. (1977). Personality effects on cognitive test performance. The Journal of Psychology, 96, 111-122.

Goolkasian, P. (1982). Test anxiety and its effects on the speed-accuracy tradeoff function. Bulletin of the Psychonomic Society, 19, 133-136.

Graham, W. K. (1977). Acceptance of ideas generated through individual and group brainstorming. Journal of Social Psychology, 101, 231-234.

Grether, W. F. (1971). Noise and human performance (AMRL-TR-70-29). Wright-Patterson Air Force Base, OH: Aerospace Medical Research Laboratory.

Grether, W. F. (1973). Human performance at elevated environmental temperature. Aerospace Medicine, 44, 747-755.

Grierson, A. T. (1975). Adaptation and motivation in sport parachuting. Unpublished Master's thesis, University of Edinburgh.

Griffiths, I. D. (1975). The thermal environment. In D. Canter & P. Stringer (Eds.), Environmental interaction (pp. 21-54). New York: International Universities Press.

Gurman, E. B. (1968). Creativity as a function of orientation and group participation. Psychological Reports, 22, 471-478.

Halse, K., Blix, A. S., Ellerstein, B., & Ursin, H. (1978). Urinary levels of epinephrine and norepinephrine in parachutist trainees. In H. Ursin, E. Baade, & S. Levine (Eds.), Psychobiology of stress: A study of coping men. New York: Academic Press.

Hamilton, P., & Copeman, A. (1969). The effect of alcohol and noise on components of a tracking and monitoring task (Research Report No. OES-518: TRC-BR-28179). London: Royal Navy Personnel Research Committee.

Hamilton, P., & Copeman, A. (1970). The effect of alcohol and noise on components of a tracking and monitoring task. British Journal of Psychology, 61, 149-156.

Hamilton, P., Hockey, G. R. J., & Quinn, J. G. (1972). Information selection, arousal, and memory. British Journal of Psychology, 63, 181-189.

Harari, O., & Graham, W. K. (1975). Tasks and task consequences as factors in individual and group brainstorming. Journal of Social Psychology, 95, 61-65.

Harris, C. S. (1968). The effects of high intensity noise on human performance (AMRL-TR-67-119). Wright-Patterson Air Force Base, OH: Aerospace Medical Research Laboratory.

Harris, C. S. (1970). Human performance effects of repeated exposure to impulsive acoustic stimulation (Research Report No. AMRL-TR-70-38). Wright-Patterson Air Force Base, OH: Aerospace Medical Research Laboratory.

Harris, C.S. (1973). The effects of different types of acoustic stimulation on performance. In W. D. Ward (Ed.), Proceedings of the International Congress on Noise as a Public Health Problem. Washington, D.C.: U.S. Environmental Protection Agency.

Harris, C. S., & Filson, G. W. (1971). Effects of noise on serial search performance (Research Report No. AMRL-TR-71-56). Wright-Patterson Air Force Base, OH: Aerospace Medical Research Laboratory.

Harris, R. M. (1981). Conceptual complexity and preferred coping strategies in anticipation of temporally predictable and unpredictable threat. Journal of Personality and Social Psychology, 41, 380-390.

Hartley, L. R. (1973). Effect of prior noise or prior performance on serial reaction. Journal of Experimental Psychology, 101, 255-261.

Hartley, L. R. (1974). Performance during continuous and intermittent noise and wearing ear protection. Journal of Experimental Psychology, 102, 512-516.

Hartley, L. R. (1976). Comparison of performance with headphone and free-field noise (Research Report No. BR-52535). London: Royal Navy Personnel Research Committee, Medical Research Council.

Hartley, L. R. (1981). Noise, attentional selectivity, serial reactions and the need for experimental power. British Journal of Psychology, 72, 101.

Haslam, D. R. (1978). A comparison of continuous operations upon the military performance of infantrymen (Exercise Early Call II) (APRE Report 4/78). Farnborough, UK: Army Personnel Research Establishment.

Haslam, D. R., & Abraham, P. (1987). Sleep loss and military performance. In G. L. Belenky (Ed.), Contemporary studies in combat psychiatry (pp. 167-184). New York: Greenwood Press.

Heimstra, N. W. (1972). Research on intermittent noise effects on Air Force target detection tasks (Research Report No. AFOSR 69-1822). Arlington, VA: Air Force Office of Scientific Research.

Hirst, W., Spelke, E. S., Reaves, C. C., Caharack, G., & Neisser, U. (1980). Dividing attention without alternation or automaticity. Journal of Experimental Psychology, General, 109, 98-117.

Hitch, G. J., and Baddeley, A. D. (1976). Verbal reasoning and working memory. Quarterly Journal of Experimental Psychology, 28, 603-621.

Hockey, G. R. J., & Hamilton, P. (1970). Arousal and information selection in short-term memory. Nature, 226, 866-867.

Holmes, D. S., & Houston, B. K. (1974). Effectiveness of situation redefinition and affective isolation in coping with stress. Journal of Personality and Social Psychology, 29, 212-218.

Horvath, S. M., & Freedman, A. (1957). The influence of cold upon the efficiency of man. Journal of Aviation Medicine, 18, 158-164.

House Armed Services Committee (1989). Iran Air flight 655 compensation (Rept. #100-119). Washington, DC: U.S. Government Printing Office.

Houston, B. K. (1968). Inhibition and the facilitating effect of noise on interference tasks. Perceptual and Motor Skills, 27, 947-950.

Houston, B. K. (1972a). Control over stress, locus of control, and response to stress. Journal of Personality and Social Psychology, 21, 249-255.

Houston, B. K. (1972b). Viability of coping strategies, denial, and response to stress. Journal of Personality, 41, 50-58.

Houston, B. K., Bloom, L. J., Burish, T. G., & Cummings, E. M. (1978). Positive evaluation of stressful experiences. Journal of Personality, 46, 205-214.

Houston, B. K. & Holmes, D. S. (1974). Effect of avoidant thinking and reappraisal for coping with threat involving temporal uncertainty. Journal of Personality and Social Psychology, 30, 382-388.

Huchingson, R. D. (1973). Effects of time constraint on closed-loop tracking performance and change in heart rate. Perceptual and Motor Skills, 36, 1195-1198.

Hughes, D. G., & Folkard, S. (1976). Adaptation to an 8-h shift in living routine by members of a socially isolated community. Nature, 264, 432-434.

Huntley, M. S., & Centybear, T. M. (1974). Alcohol, sleep deprivation and driving speed effects upon control use during driving. Human Factors, 16, 19-28.

Idzikowski, C., & Baddeley, A. D. (1983). Fear and dangerous environments. In R. Hockey (Ed.), Stress and fatigue in human performance (pp. 123-144). Chichester: Wiley.

Innes, L. G., & Allnutt, M. F. (1967). Performance measurement in unusual environments (IAM Technical Memorandum No. 298). Farnborough, England: RAF Institute of Aviation Medicine.

Jablin, F. M. (1981). Cultivating imagination: Factors that enhance and inhibit creativity in brainstorming groups. Human Communication Research, 7, 245-258.

Jablin, F. M., Seibold, D. R., & Sorenson, R. L. (1977). Potential inhibitory effects of group participation on brainstorming performance. Central States Speech Journal, 28, 113-121.

Janis, I. L. (1949). Problems related to the control of fear in combat. In Stouffer, S.A. et al. (Eds.). The American soldier: Combat and its aftermath. Princeton, NJ: Princeton University Press.

Janis, I. L. (1958). Psychological Stress. New York: Wiley.

Jemmott, J. B., & Locke, S. E. (1984). Psychosocial factors, immunologic mediation, and human susceptibility to infectious diseases: How much do we know? Psychological Bulletin, 95, 78-108.

Jerison, H. J. (1957). Performance on a simple vigilance task in noise and quiet. The Journal of the Acoustical Society of America, 29, 1163-1165.

Johnson, R. A. (1982). Comparative analysis of positive and negative lateral acceleration on isometric fatigue. Unpublished Master's thesis, Air Force Institute of Technology, Wright-Patterson AFB, OH. (AD A124752)

Johnston, W. A., Greenberg, S. N., Fisher, R. P., & Martin, D. W. (1970). Divided attention: A vehicle for monitoring memory processes. Journal of Experimental Psychology, 1, 164-171.

Jones, D. (1987). Discussion. In Ursano, R. J. (Ed.), Individual and group behavior in toxic and contained environments. Bethesda, MD: Uniformed Services University of the Health Sciences.

Jones, D., & Broadbent, D. (1979). Side effects of interference with speech by noise. Ergonomics, 22, 1073-1081.

Jones, D. M., Smith, A. P., & Broadbent, D. E. (1979). Effects of moderate intensity noise on the Bakan vigilance task. Journal of Applied Psychology, 64, 627-634.

Jones, E., Hennessy, R., & Deutsch, S. (1985). Human factors aspects of simulation. Washington, DC: National Academy Press.

Kahneman, D. (1973). Attention and effort. Englewood Cliffs, NJ: Prentice-Hall.

Kahneman, D. (1975). Effort, recognition and recall in auditory attention. Attention and Performance, 6, 65-80.

Kallman, W. M., & Isaac, W. (1977). Altering arousal in humans by varying ambient sensory conditions. Perceptual and Motor Skills, 44, 19-22.

Kane, W. D. (1986). Stress and aircraft maintenance performance in a combat environment. Proceedings of the 10th symposium, Psychology in the Department of Defense. Colorado Springs, CO: United States Air Force Academy.

Keele, S. W. (1973). Attention and human performance. Pacific Palisades, CA: Goodyear.

Keinan, G. (1987). The effects of expectations and feedback. Journal of Applied Social Psychology, 18, 355-373.

Keinan, G., Friedland, N., & Ben-Porath, Y. (1987). Decision-making under stress: Scanning of alternatives under physical threat. Acta Psychologica, 64, 219-228.

Kerr, N. L., & Bruun, S. E. (1983). Dispensability of member effort and group motivation losses: Free-rider effects. Journal of Personality and Social Psychology, 44, 78-94.

Kirk, R. E., & Hecht, E. (1963). Maintenance of vigilance by programmed noise. Perceptual and Motor Skills, 16, 553-560.

Koelega, H. S. (1986). Noise and vigilance: An evaluative review. Human Factors, 28, 465-481.

Kollar, E. J., Slater, G. R., Palmer, J. O., Docter, R. F., & Mandell, A. J. (1966). Stress in subjects undergoing sleep deprivation. Psychosomatic Medicine, 28, 101-113.

Kopacz, F. R., & Smith, B. S. (1971). Sex differences in skin conductance measures as a function of shock threat. Psychophysiology, 8, 293-303.

Krueger, G. P. (1989). Sustained work, fatigue, sleep loss and performance: A review of the issues (TR No. 89-22). Fort Rucker, AL: USAARL. (AD A215234)

Kryter, K. D. (1971). Non-auditory effects of noise. Washington, DC: National Academy of Sciences - National Research Council Committee on Hearing, Bioacoustics, and Biomechanics. (NTIS No. AD728426)

Kuhmann, W., Boucsein, W., Schaefer, F., & Alexander, J. (1987). Experimental investigation of psychophysiological stress-reactions induced by different system response times in human-computer interaction. Ergonomics, 30, 933-943.

Kurz, R. B. (1964). Effects of three kinds of stressors on human learning and performance. Psychological Reports, 14, 161-162.

Labuc, S. (1984). Training to cope with psychological stress. Paper prepared for the Technical Panel on Training Technology, The Technical Cooperation Program (TTCP).

Lamm, H., & Trommsdorf, G. (1973). Group versus individual performance on tasks requiring ideational proficiency (brainstorming). European Journal of Social Psychology, 3, 361-387.

Landers, D. M. & Martens, R. (1971). The influence of birth order and situational stress on motor performance. Psychonomic Science, 24, 165-167.

Latane, B., Williams, K., & Harkins, S. (1979). Many hands make light the work: The causes and consequences of social loafing. Journal of Personality and Social Psychology, 37, 822-832.

Lazarus, R. S. (1966). Psychological stress and the coping process. New York: McGraw-Hill.

Lee, L. C. (1961). The effects of anxiety level and shock on a paired-associate verbal task. Journal of Experimental Psychology, 61, 213-217.

Lewis, R. P. (1971). The effects of combined environmental factors on human performance of a manual task: Noise and temperature. Unpublished master's thesis, Texas A & M University.

Link, S. W. (1971). Applying RT deadlines to discrimination reaction time. Psychonomic Science, 25, 355-358.

Link, S. W., & Tindall, A. D. (1971). Speed and accuracy in comparative judgements of line length. Perception and Psychophysics, 9, 284-288.

Lisper, H., & Kjellberg, A. (1972). Effects of 24-hour sleep deprivation on rate of decrement in a 10-minute auditory reaction time task. Journal of Experimental Psychology, 96, 287-290.

Locke, E. A. (1968). Toward a theory of task motivation and incentives. Organizational Behavior and Human Performance, 3, 157-189.

Loeb, M., Barron, T. A., & Burda, E. S. (1954). A preliminary investigation of the effects of whole-body vibration and noise (Report No. 45). Fort Knox, KY: Army Medical Research Laboratory.

Loeb, M., & Jones, P. D. (1978). Noise exposure, monitoring and tracking performance as a function of signal bias and task priority. Ergonomics, 21, 265-272.

Loeb, M., Jones, P. D., & Cohen, A. (1976). Effects of noise on non-auditory sensory functions and performance (NIOSH-76-176). Cincinnati, OH: National Institute for Occupational Safety and Health.

London, P., Ogle, M. E., & Unikel, I. P. (1968). Effects of hypnosis and motivation on resistance to heat stress. Journal of Abnormal Psychology, 73, 532-541.

Lovallo, W. R., & Pishkin, V. (1980). Performance of Type A (coronary-prone) men during and after exposure to uncontrollable noise and task failure. Journal of Personality and Social Psychology, 38, 963-971.

Loveland, N. T., & Williams, H. I. (1963). Adding, sleep loss, and body temperature. Perceptual and Motor Skills, 16, 923-929.

Lovingood, B. W., Blyth, C. S., Peacock, W. H., & Lindsay, R. B. (1967). Effects of d-amphetamine sulfate, caffeine, and high temperature on human performance. Research Quarterly, 38, 64-71.

Lubin, A., Hord, D. J., Tracy, M. L., & Johnson, L. C. (1976). Effects of exercise, bedrest and napping on performance decrement during 40 hours. Psychophysiology, 13, 334-339.

Lulofs, R., Wennekens, R., & Van Houtem, J. V. (1981). Effect of physical stress and time pressure on performance. Perceptual and Motor Skills, 52, 787-793.

Madsen, D. B., & Finger, J. R. (1978). Comparison of a written feedback procedure, group brainstorming, and individual brainstorming. Journal of Applied Psychology, 63, 120-123.

Maginn, B. K., & Harris, R. J. (1980). Effects of anticipated evaluation on individual brainstorming performance. Journal of Applied Psychology, 65, 219-225.

Marshall, S. L. A. (1947). Men Against Fire. New York: William Morrow.

Marteniuk, R. G., & Wenger, H. A. (1970). Facilitation of pursuit rotor learning by induced stress. Perceptual and Motor Skills, 31, 471-477.

Martens, R., & Landers, D. M. (1970). Motor performance under stress: A test of the inverted-U hypothesis. Journal of Personality and Social Psychology, 16, 29-37.

May, J., & Kline, P. (1987). Measuring the effects upon cognitive abilities of sleep loss during continuous operations. British Journal of Psychology, 78, 443-455.

May, J., & Kline, P. (1988). An objective measure of fatigue derived from a set of brief tasks. Work and Stress, 2(1), 59-70.

McCormick, E. J., & Sanders, M. S. (1982). Human factors in engineering and design. New York: McGraw Hill.

McKinney, F. (1933). Certain emotional factors in learning and efficiency. Journal of General Psychology, 9, 101-116.

McLeod, P. (1977). A dual task response modality effect: Support for multiprocessor models of attention. Quarterly Journal of Experimental Psychology, 29, 651-667.

Mears, J. D., & Cleary, P. J. (1980). Anxiety as a factor in underwater performance. Ergonomics, 23, 549-557.

Mech, E. V. (1953). Factors influencing routine performance under noise: I. The influence of "set". The Journal of Psychology, 35, 283-298.

Mertens, H. W., & Collins, W. E. (1986). The effects of age, sleep deprivation, and altitiude on complex performance. Human Factors, 28, 541-551.

Millar, K. (1979). Word recognition in loud noise. Acta Psychologica, 43, 225-237.

Milton, G. A. (1965). Enthusiasm vs. effectiveness in group and individual problem-solving. Psychological Reports, 16, 1197-1202.

Monat, A., Averill, J. R., & Lazarus, R. S. (1972). Anticipatory stress and coping reactions under various conditions of uncertainty. Journal of Personality and Social Psychology, 24, 237-253.

Moore, J. J., & Massaro, D. W. (1973). Attention and processing capacity in auditory recognition. Journal of Experimental Psychology, 99, 49-54.

Moran, S. L. V., & Loeb, M. (1977). Annoyance and behavioral aftereffects following interfering and noninterfering aircraft noise. Journal of Applied Psychology, 62, 719-726.

Moray, N. (1967). Where is attention limited. A survey and a model. Acta Psychologica, 27, 84-92.

Moray, N., & Fitter, M. (1973). A theory and the measurement of attention: Tutorial review. In S. Kornblum (Ed.), Attention and Performance: Vol. IV. New York: Academic Press.

Morris, L. W., & Liebert, R. M. (1969). Effects of anxiety on timed and untimed intelligence tests. Journal of Consulting and Clinical Psychology, 33, 240-244.

Mosteller, F. M., & Bush, R. R. (1954). Selected quantitative techniques. In G. Lindzey (Ed.), Handbook of social psychology: Vol. 1. Theory and method (pp. 289-334). Cambridge, MA: Addison-Wesley.

Mowbray, G. H. (1953). Simultaneous vision and audition: The comprehension of prose passages with varying levels of difficulty. Journal of Experimental Psychology, 46, 365-372.

Mullen, B. (1986). BASIC Meta-analysis: A description of a statistical package. Behavior Research Methods, Instruments, and Computers, 18, 165-167.

Mullen, B. (1989). Advanced BASIC meta-analysis. Hillsdale, NJ: Erlbaum.

Mullen, B., & Baumeister, R. F. (1987). Group effects on self-attention and performance: Social loafing, social facilitation, and social impairment. In C. Hendrick (Ed.), Review of Personality and Social Psychology. Beverly Hills, CA: Sage.

Mullen, B., & Rosenthal, R. (1985). BASIC meta-analysis: Procedures and programs. Hillsdale, NJ: Erlbaum.

Mullen, B., Salas, E., & Driskell, J. E. (1989). Salience, motivation, and artifact as contributions to the relation between participation rate and leadership. Journal of Experimental Social Psychology, 25, 545-559.

Navon, D., & Gopher, D. (1979). On the economy of the human processing system. Psychological Review, 86, 254-255.

Norman, D. (1968). Toward a theory of memory and attention. Psychological Review, 75, 522-536.

Norton, R. (1970). The effects of acute sleep deprivation on selective attention. British Journal of Psychology, 61(2), 157-161.

O'Malley, J. J., & Poplawsky, A. (1971). Noise-induced arousal and breadth of attention. Perceptual and Motor Skills, 33, 887-890.

Pape, T., & Bolle, I. (1984). Einfallsproduktion von Individuen und dyaden unter "brainstorming"-bedingungen. Psychologische Beitrage, 26, 459-468.

Pearson, K. (1933). On a method of determining whether a sample size n supposed to have been drawn from a parent population having a known probability integral has probably been drawn at random. Biometrika, 25, 379-410.

Pepler, R. D. (1958). Warmth and performance: An investigation in the tropics. Ergonomics, 2, 63-68.

Percival, L., & Loeb, M. (1980). Influence of noise characteristics on behavioral aftereffects. Human Factors, 22, 341-352.

Pervin, L. A. (1963). The need to predict and control under conditions of threat. Journal of Personality, 31, 570-587.

Plutchik, R. (1961). Effect of high-intensity intermittent sound on compensatory tracking and mirror tracing. Perceptual and Motor Skills, 12, 187-194.

Poulton, E. C. (1978). A new look at the effects of noise: A rejoiner. Psychological Bulletin, 85, 1068-1079.

Rachman, S. J. (1983). Development of courage in military personnel in training and performance in combat situations (Research Report No. 1338). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Radloff, R., & Helmreich, R. (1968). Groups under stress: Psychological research in SEALAB II. New York: Appleton-Century-Crofts.

Ramsey, J. D. (1983). Heat and cold. In G. R. J. Hockey (Ed.), Stress and fatigue in human performance (pp. 33-60). Chichester: Wiley.

Reim, B., Glass, D. C., & Singer, J. E. (1971). Behavioral consequences of exposure to uncontrollable and unpredictable noise. Journal of Applied Social Psychology, 1, 44-56.

Repko, J. D., Brown, B. R., & Loeb, M. (1974). Effects of continuous and intermittent noise on sustained performance (ITR-74-29). Arlington, VA: U.S. Army Organizations and Systems Research Laboratory. (AD-785740)

Rodin, J. (1976). Density, perceived choice, and response to controllable and uncontrollable outcomes. Journal of Experimental and Social Psychology, 12, 564-578.

Rosenthal, R. (1961). On the social psychology of the psychological experiment: With particular reference to experimenter bias. In H. W. Riecken (Chair), On the social psychology of the psychological experiment. Symposium conducted at the meeting of the American Psychological Association, New York.

Rosenthal, R. (1984). Meta-analytic procedures for social research. Beverly Hills, CA: Sage.

Rotter, G. S., & Portugal, S. M. (1969). Group and individual effects in problem solving. Journal of Applied Psychology, 53, 338-341.

Russell, R. W. (1957). Effects of variations in ambient temperature on certain measures of tracking skill and sensory sensitivity (Report 300). Fort Knox, KY: U.S. Army Medical Research Laboratory.

Ryan, D. E. (1961). Motor performance under stress as a function of the amount of practice. Perceptual and Motor Skills, 13, 103-106.

Ryan, D. E. (1962). Effects of stress on motor performance and learning. Research Quarterly, 33, 111-119.

Sage, G. H., & Bennett, B. (1973). The effects of induced arousal on learning and performance of a pursuit motor skill. Research Quarterly, 44, 140-149.

Salame, P., & Wittersheim, G. (1978). Selective noise disturbance of the information input in short-term memory. Quarterly Journal of Experimental Psychology, 30, 693-704.

Samuel, W. M. S. (1963). Noise and the shifting of attention. Quarterly Journal of Experimental Psychology, 16, 264-267.

Sanders, G. S. (1981). Driven by distraction: An integrative review of social facilitation theory and research. Journal of Experimental Social Psychology, 17, 227-251.

Schwartz, S., & Winograd, B. (1954). Preparation of soldiers for atomic maneuvers. Journal of Social Issues, 10, 42-52.

Seligman, M. E. P. (1975). Helplessness. San Francisco: Freeman.

Shaffer, L. H. (1975). Multiple attention in continuous verbal tasks. In P. M. A. Rabbitt & S. Dornic (Eds.), Attention and Performance (pp. 157-167). London: Academic Press.

Sherrod, D. (1974). Crowding, perceived control and behavioral aftereffects. Journal of Applied Social Psychology, 4, 171-186.

Sherrod, D. R., Hage, J. N., Halpern, P. L., & Moore, B. S. (1977). Effects of personal causation and perceived control on responses to an aversive environment: The more control the better. Journal of Experimental Social Psychology, 13, 14-27.

Siegel, A. I., Kopstein, F. F., Federmen, P. J., Ozkaptan, H., Slifer, W. E., Hegge, F. W., & Marlowe, D. H. (1981). Management of stress in Army operations (Research Product No. 81-19). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Simpson, G. C., Coz, T., & Rothschild, D. R. (1974). The effects of noise stress on blood glucose level and skilled performance. Ergonomics, 17, 481-487.

Smith, A. P. (1982). The effects of noise and task priority on recall of order and location. Acta Psychologica, 51, 245-255.

Smith, A. P., & Broadbent, D. E. (1980). Effects of noise on performance on embedded figures tasks. Journal of Applied Psychology, 65, 246-248.

Smith, A. P., & Broadbent, D. E. (1981). Noise and levels of processing. Acta Psychologica, 47, 129-142.

Smith, A. P., Jones, D. M., & Broadbent, D. E. (1981). The effects of noise on recall of categorized lists. British Journal of Psychology, 72, 299-316.

Snedecor, G. W. (1946). Statistical methods (4th ed). Ames: Iowa State College Press.

Solov'yeva, I. B. (1981). Psychological training of an astronaut operator under the conditions of emotional stress (Trans.) (Report No. USAMILA-L-0605). Fort Detrick, MD: U.S. Army Medical Intelligence and Information Agency.

Spelke, E., Hirst, W., & Neisser, U. (1976). Skills of divided attention. Cognition, 4, 215-230.

Staub, E., & Kellet, D. S. (1972). Increasing pain tolerance by information about aversive stimuli. Journal of Personality and Social Psychology, 21, 198-203.

Staub, E., Tursky, B., & Schwartz, G. E. (1971). Self-control and predictability: Their effects on reactions to aversive stimuli. Journal of Personality and Social Psychology, 18, 157-162.

Staw, R. M., Sandelands, L. E., & Dutton, J. E. (1981). Threat-rigidity effects in organizational behavior: A multi-level analysis. Administrative Science Quarterly, 26, 501-524.

Stein, M. I. (1968). Creativity. In E. Borgatta and W. Lambert (Eds.), Handbook of personality theory and research (pp. 900-942). Chicago: Rand-McNally.

Stouffer, S. A., Lumsdaine, A. A., Lumsdaine, M. H., Williams, R. M., Smith, M. B., Janis, I. L., Star, S. A., & Cottrell, L. S. (1949). The American soldier: Combat and its aftermath. Princeton, NJ: Princeton University Press.

Strausbaugh, L. J., & Roessler, R. (1970). Ego strength, skin conductance, sleep deprivation, and performance. Perceptual and Motor Skills, 31, 671-677.

Streufert, S., & Streufert, S. C. (1981). Stress and information search in complex decision making: Effects of load and time urgency (Technical Report No. 4). Arlington, VA: Office of Naval Research.

Sullivan, L. (1976). Selective attention and secondary message analysis. A reconsideration of Broadbent's filter model of selective attention. Quarterly Journal of Experimental Psychology, 28, 167-178.

Szpiler, J. A., & Epstein, S. (1976). Availability of an avoidance response as related to autonomic arousal. Journal of Abnormal Psychology, 85, 73-82.

Taylor, D. W., Berry, P. C., & Block, C. H. (1958). Does group participation when using brainstorming facilitate or inhibit creative thinking? Administrative Science Quarterly, 3, 23-47.

Teichner, W. H., Arees, E., & Reilly, R. (1963). Noise and human performance: A psychological approach. Ergonomics, 6, 83-97.

Teichner, W. H., & Wehrkamp, R. F. (1954). Visual-motor performance as a function of short-duration ambient temperature. Journal of Experimental Psychology, 47, 447-450.

Thackray, R. I., & Pearson, D. W. (1968). Effects of cognitive appraisal of stress on heart rate and task performance. Perceptual and Motor Skills, 27, 651-658.

Thackray, R. I., & Touchstone, R. M. (1979). Effects of noise exposure on performance of a simulated radar task (FAA-AM-79-24). Washington, DC: Federal Aviation Administration, Office of Aviation Medicine.

Theologus, G. C., Wheaton, G. R., & Fleishman, E. A. (1974). Effects of intermittent, moderate intensity noise stress on human performance. Journal of Applied Psychology, 59, 539-547.

Theologus, G. C., Wheaton, G. R., Mirabella, A., Brahley, R. E., & Fleishman, E. A. (1973). Development of a standardized battery of performance tests for the assessment of noise stress effects (Report No. NASA CR-2149). Washington, DC: National Aeronautics and Space Administration.

Thompson, S.C. (1981). Will it hurt less if I can control it? A complex answer to a simple question. Psychological Bulletin, 90, 89-101.

Thorndike, R. L. (1933). The effect of the interval between test and retest on the constancy of the IQ. Journal of Educational Psychology, 24, 543-549.

Torrence, E. P. (1970). Influence of dyadic interaction on creative functioning. Psychological Reports, 26, 391-394.

Treisman, A. M. (1964). The effect of irrelevant material on the efficiency of selective listening. American Journal of Psychology, 77, 533-546.

Treisman, A. M. (1969). Strategies and models of selective attention. Psychological Review, 76, 282-299.

Treisman, A. M., and Davies, A. (1973). Divided attention to ear and eye. In S. Kornblum (Ed.), Attention and Performance: Volume IV (pp. 101-117). London: Academic Press.

Tulving, E., & Lindsay, P. H. (1967). Identification of simultaneously presented simple visual and auditory stimuli. In A. F. Sanders (Ed.), Attention and Performance: Vol. I. Amsterdam: North-Holland.

Vickroy, S. C., Shaw, J. B., & Fisher, C. D. (1982). Effects of temperature, clothing, and task complexity on task performance and satisfaction. Journal of Applied Psychology, 67, 97-102.

Villoldo, A., & Tarno, R. L. (1984). Measuring the performance of EOD equipment and operators under stress (Technical Report No. 270). Indian Head, MD: Naval Explosive Ordnance Disposal Technical Center.

Von Wright, J., & Nurmi, L. (1979). Effect of white noise and irrelevant information on speeded classification: A developmental study. Acta Psychologica, 43, 157-166.

Von Wright, J., & Vauras, M. (1980). Interactive effects of noise and neuroticism on recall from semantic memory. Scandinavian Journal of Psychology, 21, 97-101.

Wachtel, P. L. (1968). Anxiety, attention, and coping with threat. Journal of Abnormal Psychology, 73, 137-143.

Ward, S. L., & Poturalski, R. J. (1983). Maze-solving as a performance measurement tool for human operators under time stress (AFAMRL-TR-83-052). Wright-Patterson AFB, OH: Air Force Aerospace Medical Research Laboratory, Human Engineering Division. (AD A133394)

Warner, H. D., & Heimstra, N. W. (1971). Effects of intermittent noise on visual search tasks of varying complexity. Perceptual and Motor Skills, 32, 219-226.

Warner, H. D., & Heimstra, N. W. (1972). Effects of noise intensity on visual target-detection performance. Human Factors, 14, 181-185.

Warner, H. D., & Heimstra, N. W. (1973). Target-detection performance as a function of noise intensity and task difficulty. Perceptual and Motor Skills, 36, 439-442.

Webb, W. B. (1985). A further analysis of age and sleep deprivation effects. Psychophysiology, 22, 156-161.

Webb, W. B., & Levy, C. M. (1982). Age, sleep deprivation and performance. Psychophysiology, 19, 272-276.

Weinstein, N. D. (1974). Effect of noise on intellectual performance. Journal of Applied Psychology, 59, 548-534.

Weinstein, N. D. (1977). Noise and intellectual performance: A confirmation and extension. Journal of Applied Psychology, 62, 104-107.

Wherry, R., & Curran, P. (1966). A model for the study of some determinants of psychological stress: Initial experimental research. Organizational Behavior and Human Performance, 1, 226-251.

Wickens, C. D. (1980). The structure of attentional resources. In R. Nickerson (Ed.), Attention and performance: Vol. VIII. Hillsdale, NJ: Erlbaum.

Wickens, C. D. (1984). Processing resources in attention. In R. Parasuraman & D. R. Davies (Eds.), Attention and performance: Volume IV. London: Academic Press.

Wickens, C. D. & Flach, J. M. (1988). Information processing. In E. L. Wiener & D. C. Nagel (Eds.), Human factors in aviation. Academic Press: San Diego.

Wickens, C., & Rouse, W. (1985). The role of human factors in military R&D. Paper presented at the Federation of Behavioral, Psychological, and Cognitive Sciences, Washington, DC.

Wilbanks, W. A., Webb, W. B., & Tolhurst, G. C. (1956). A study of intellectual activity in a noisy environment. Pensacola, FL: U.S. Naval School of Aviation Medicine.

Wilding, J., Mohindra, N., & Breen-Lewis, K. (1982). Noise effects in free recall with different orienting tasks. British Journal of Psychology, 73, 479-486.

Wilkinson, R. T. (1964). Effects of up to 60 hours' sleep deprivation on different types of work. Ergonomics, 7, 175-186.

Williams, H. L., Beaver, W. S., Spence, M. T., & Rundell, O. H. (1969). Digital and kinesthetic memory with interpolated information processing. Journal of Experimental Psychology, 80, 530-536.

Williams, H. L., Gieseking, C. F. (1966). Some effects of sleep loss on memory. Perceptual and Motor Skills, 23, 1287-1293.

Williams, H. L., Kearney, O. F., & Lubrin, A. (1965). Signal uncertainty and sleep loss. Journal of Experimental Psychology, 69, 401-407.

Williams, H. L., & Lubin, A. (1967). Speeded addition and sleep loss. Journal of Experimental Psychology, 73, 313-317.

Williams, H. L., Lubin, A., & Goodnow, J. J. (1959). Impaired performance with acute sleep loss. Psychological Monographs, 73 (Whole No. 484).

Williams, K. B., Harkins, S., & Latane, B. (1981). Identifiability as a deterrent to social loafing: Two cheering experiments. Journal of Personality and Social Psychology, 40, 303-311.

Williams, R. M. (1984). Field observations and surveys in combat zones. Social Psychology Quarterly, 47, 186-192.

Wohlwill, J. F., Nasar, J. L., DeJoy, D. M., Foruzani, H. H. (1976). Behavioral effects of a noisy environment: Task involvement versus passive exposure. Journal of Applied Psychology, 61, 67-74.

Woodhead, M. M. (1964). The effect of bursts of noise on an arithmetic task. American Journal of Psychology, 77, 627-633.

Wright, P. (1974). The harassed decision maker: Time pressures, distractions, and the use of evidence. Journal of Applied Psychology, 59, 555-561.

Wright. J. V., & Nurmi, L. (1970). Effects of white noise and irrelevant information on speeded classification: A developmental study. Acta Psychologica, 43, 157-166.

Wyon, D. P. (1974). The effects of moderate heat stress on typewriting performance. Ergonomics, 17, 309-318.

Yamamoto, T. (1984). Human problem solving in a maze using computer graphics under an imaginary condition of "fire." Japanese Journal of Psychology, 55, 43-47.

Yellot, J. I. (1971). Correction for fast guessing and the speed-accuracy tradeoff in choice reaction time. Journal of Mathematical Psychology, 8, 159-199.

Yerkes, R. (1918). Psychology in relation to the war. Psychological Review, 25, 85-115.

Zajonc, R. B. (1965). Social facilitation. Science, 149, 269-274.

Zakay, D., & Wooler, S. (1984). Time pressure, training and decision effectiveness. Ergonomics, 27, 273-284.

*U.S. GOVERNMENT PRINTING OFFICE: 1992-670-990-No Program